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Volume 4 AUGUST, 1934 Number 2

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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NOTICE

Articles submitted for publication to the JOURNAL OF SEDIMENTARY PETROLOGY should have a prefatory abstract and sufficient postage should be sent by the author to prepay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 2, PP. 55–59, TABLE 1,
AUGUST, 1934

THE PETROLOGY OF THE TOMBIGBEE SANDS OF EASTERN MISSISSIPPI

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New Mexico School of Mines

ABSTRACT

Study of the Cretaceous Tombigbee member of the Eutaw formation of Mississippi indicates that the materials of the formation were derived chiefly from the crystalline complex of the Southern Appalachians under conditions of rather low relief and mature weathering. The materials are considered to have suffered relatively short transportation and to have been deposited above wave base in an agitated and very shallow transgressing sea.

The Tombigbee sand member of the Eutaw formation of Cretaceous age takes its name from typical exposures in Plymouth Bluff along the Tombigbee river about 4 miles northwest of Columbus, Mississippi. At this locality some 35 feet of greensand marls are exposed, overlain comformably by several feet of Selma Chalk. The Tombigbee member in northeastern Mississippi is about 150 feet thick and has been traced northward almost to the Tennessee line.[1] On the whole it is massive and unindurated, and much of it is nonfossiliferous. However, at the type locality two or three indurated layers are found, and in many places fossils are abundant. The most distinctive fossil is the large thick pelecypod *Exogyra ponderosa* Roemer. In one of the indurated layers excellent specimens of *Mortoniceras texanum* Roemer have been found. Other forms fairly abundant are species of *Ostrea, Baculites, Trigonia, Inoceramus, Nautilus,* and possibly others.

Samples for petrographic study were collected at the type locality during the summer of 1932. Fossil collections were made and stratigraphic relations studied several years ago. It is hoped that this paper may be a slight contribution toward a better understanding of Cretaceous history in the Gulf region and possibly be of some assistance in correlating subsurface sections across the state of Mississippi.

GRADE SIZES

The Tombigbee sands are well sorted, about 90 per cent passing a 100-mesh screen and but very little passing the 200-mesh screen. The great majority of the grains range from 0.13 mm. to 0.15 mm. in diameter and only a few are as large as 0.25 mm. in diameter. On the Wentworth scale the sands are thus seen to be of fine grade.[2]

[1] Stephenson, L. W., Logan, Wm., and Waring, G. A., Ground water resources of Mississippi: *U. S. Geol. Survey, Water Supply Paper* 576, p. 32, 1928.

[2] Wentworth, C. K., Grade and class terms for clastic sediments: *Jour. Geology*, vol. 30, pp. 377-392, 1922.

SHAPES OF GRAINS

The detrital grains in the Tombigbee sands are characterized by their lack of abrasion. Virtually no grains are rounded, and only a few are subrounded. The great majority are angular and subangular. This holds true not only for the quartz but for the accessory minerals as well.

MINERAL COMPOSITION

LIGHT MINERALS

Quartz.—Quartz comprises the great body of the sand. The grains are characterized by their uniform fineness, and their lack of abrasion, frosting, and secondary enlargement.

Glauconite.—This mineral is found both in the light and heavy fractions. Next to quartz it is the most abundant mineral. In size, the grains are fine, and in shape, they are nodular or irregular. In color, they are light-green to blackish-green. Some are decomposing to limonite. The irregular shapes of some of the grains suggest that they may have been formed as casts of foraminifera.

Muscovite.—Muscovite is plentiful in the sands. It occurs in cleavage flakes that are considerably larger than the non-micaceous detritals. It is probably an iron-rich muscovite, as indicated by a smaller optic angle and higher indices of refraction than is shown by the iron-free variety.

Orthoclase.—Orthoclase grains are present only in very small numbers. The mineral is found as small irregular or rectangular grains, colorless, and somewhat clouded with alteration products.

Chlorite.—Chlorite is found but rarely in the Tombigbee sands. The grains are subangular, greenish, micaceous, and slightly pleochroic. They are believed to be detrital and are undoubtedly decomposition products after ferromagnesian minerals.

HEAVY MINERALS

Epidote.—Epidote is the most abundant heavy mineral in the sands. At least two varieties are recognized. One is nearly colorless and nonpleochroic; the other is yellow-brown and markedly pleochroic. This does not necessarily imply two different sources for the epidote, as it is known that this mineral may show different characteristics in the same rock.

Garnet.—Garnet is next to epidote in abundance. The grains are irregular and fractured, pale-pink to colorless, and a very few show etched surfaces.

Kyanite.—Kyanite is almost as abundant as garnet. Most of it occurs in the form of subangular prismatic grains, elongated in the direction of the *c* axis, with traces of the basal cleavage frequently evident. Other grains are somewhat stumpy.

Ilmenite.—Ilmenite, likewise, is almost as abundant as garnet. It occurs in irregular, subangular grains, a few of which have altered to leucoxene.

Tourmaline.—Tourmaline is fairly abundant, being only slightly less plentiful than kyanite. Both brown and blue varieties are present, although the brown variety is much more abundant. The blue variety occurs in irregular fractured grains, many of which show nearly centered interference figures. Many of the brown grains are also irregular, but a considerable

number are prismatic with varied terminations.

Heavy minerals that are found in much smaller numbers than the above described five species are staurolite, sillimanite, zircon, titanite, and biotite.

Staurolite.—Staurolite is found as irregular fractured grains for the most part, but in a few cases nearly perfect euhedra are seen. The color is a deep brown, and the pleochroism is marked.

Sillimanite.—Sillimanite is present in grains much longer, more narrow and fibrous than kyanite. The grains are colorless and transparent.

Zircon.—The zircon grains vary considerably in form. Some are prismatic and show good pyramidal terminations, as if deposited in essentially the shape they had when derived from the parent rock. Others show much abrasion and rounding, as if they had a much longer sedimentary history, but in no case is the rounding extreme.

Titanite.—Titanite occurs in irregular shaped grains, some of which are slightly rounded, whereas others are more ragged. The color is a pale yellowish-brown. Important diagnostic features are interference figures showing extreme dispersion, and absence of extinction under crossed nicols.

Biotite.—Biotite is a very rare mineral in the Tombigbee sands. It is found as small cleavage flakes with ragged edges. The color is a deep brown, and the pleochroism is marked.

NATURAL HISTORY OF THE SANDS

Sources of the Sediments.—The mineralogical and physical characters of the sands point to crystalline rocks as the immediate source of the sediments. Moreover, metamorphic rocks, especially schists, gneisses, and altered impure limestones, evidently were the greatest contributors. This is shown by the abundance of quartz, muscovite, epidote, kyanite, and garnet, and the presence of staurolite and sillimanite. That plutonic rocks and high temperature veins of several types also contributed is suggested by the presence of ilmenite, zircon, titanite, tourmaline, and orthoclase, as well as by quartz, muscovite, and biotite.

The most logical source of sediments is considered to have been the crystalline rocks of pre-Cambrian and Early Paleozoic age in the Southern Appalachians. This great region is so complex and little understood that only a general statement can be made concerning source rocks, but gneisses, schists, metamorphosed limestones, and various kinds of igneous rocks are known to occur across Alabama, Georgia, and the Carolinas, not far from the sites of deposition in Tombigbee time.

Crystalline rocks, rather than sediments, are considered the immediate source of the sands because of the lack of abrasion of the sand grains. If the sediments had passed through more than one cycle of erosion it appears likely that the degree of rounding would have been much greater than is found to be the case. The only suggested exception to this conclusion is in the case of some of the zircons, which are much abraded as if they had an intermediate period of deposition. Therefore, a small part of the sand may have been derived from older sediments.

Environmental Conditions at Places of Origin.—It is observed that the mineral suite of the sands is composed almost entirely of stable or moderately stable minerals. Feldspars and ferromagnesian minerals, and other unstable minerals are all but lacking. It is possible that these unstable minerals were not present to any extent in the source rocks, but this appears rather improbable, inasmuch as small amounts of feldspar and biotite are present. Moreover, such a large area of highly complex rocks probably would have unstable minerals in abundance. Another explanation of the absence of unstable minerals is that they may have been worn out in transportation. But the sands on the whole do not show the effects of long transportation. It is considered more probable that during Tombigbee time the relief of the Southern Appalachians was not great in the source regions, and the climate was at least moderately warm and moist, so that weathering tended to go to maturity. Thus, minerals of low resistance were destroyed.

Transportation.—The sands were undoubtedly transported by streams from the sites of origin to those of deposition as there is no evidence that any other agent played even a minor rôle in transportation. Inasmuch as the sand is of fine grade over considerable extent, it appears probable that only sand of this type was available to the streams, and that their load was only a small part of their actual capacity, so that excellent sorting was obtained. This condition is to be expected if the sands were derived mainly from rocks weathered to maturity on gentle terranes. However, it must be kept in mind that in regard to sorting it is not possible to determine how much of the sorting was done by the streams and how much by the sea. As previously stated, the distance of transportation is not believed to have been great.

Environments of Deposition.—The abundance of heavy molluscan remains indicates that the Tombigbee sea was very shallow. Evidently, the shore line lay only a relatively short distance to the northeast of the present exposures, and the submarine shelf must have had a very gentle dip seaward. The waves and currents were probably strong, agitating the water to a high degree, sorting the sediments still further and spreading them north and south in a uniform blanket over the floor of the sea. Further evidence of considerable agitation is found in the abundance of glauconite, which appears to be favored in its origin by agitated marine waters.

Over much of this region the thickness of the Tombigbee member is probably greater than the depth of the sea in which it was deposited. Undoubtedly, the sea gradually transgressed the lands to the northeast, covering the sites of earlier deposition with new material and not permitting the waves to remove the great body of sands that had been deposited above wave base.

SUMMARY

The important facts and deductions derived from the study of the Tombigbee sands are as follows:

1. The light minerals (sp. gr. <3.0) in the sands include quartz, glauconite,

muscovite, orthoclase, and chlorite, abundant in the order named.

2. The heavy minerals (sp. gr. >3.0) include epidote, garnet, kyanite, ilmenite, tourmaline, staurolite, sillimanite, zircon, titanite, leucoxene, and biotite, abundant in the order named.

3. The sands are well sorted, over 90 per cent of the grains being of fine grade size.

4. The great majority of the grains are angular or subangular; rounded or subrounded grains are extremely rare.

5. The crystalline complex of the Southern Appalachians is believed to have been the immediate source of the sediments; sedimentary rocks apparently contributed very minor amounts.

6. The relief of source areas is considered to have been slight, and the climate moderately warm and humid, permitting weathering to go to maturity, or nearly so.

7. The sands were transported by streams carrying much less than capacity loads. The streams had relatively low gradients and rather short courses to the sea.

8. The sands were deposited above wave base in a very shallow transgressing sea, whose waters were much agitated.

TABLE I. *Summary of the percentages of heavy minerals.*

Mineral		Mineral	
Epidote	A	Titanite	R
Garnet	C	Sillimanite	R
Kyanite	C	Staurolite	R
Ilmenite	C	Tourmaline (blue)	R
Tourmaline (brown)	P	Leucoxene	R
Zircon	R	Biotite	R

Key

		Per cent
Flood	F	75—100
Dominant	D	50— 75
Abundant	A	25— 50
Common	C	10— 25
Present	P	5— 10
Rare	R	1— 5
Trace	X	Less than 1

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 2, PP. 60–64, FIGS. 1–4,
AUGUST, 1934

THE PART PLAYED BY SOME TIDAL PLANTS IN THE FORMATION OF CLAY RHIZOCONCRETIONS

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ABSTRACT

The concretions studied here are actually in the making on the tidal shore of a portion of the Saint Lawrence River. The *nuclei* around which they form are roots of *Scirpus rufus* and *Juncus balticus* var. *littoralis*. The roots grow vertically in gray-blue clay. The decay of roots causes clay oxidation, the results of which are ochreous cylinders more compact than the original and surrounding clay. The periodic impact of tidal waves releases the concretions from the matrix and the spring tides carry them to the upper part of the shore.

The tubular ochreous concretions described in this paper were found on the beach of Bellechasse Bay (Saint-Vallier, Bellechasse County, Province of Quebec) where, in 1926, I made a survey of the tidal flora. They are associated with Pleistocene fossils washed from the beach bank by waves and form a line about 200 feet long at high tide level (fig. 1). The ochreous color of the concretions contrasts strongly with the gray-blue clay composing the shore.

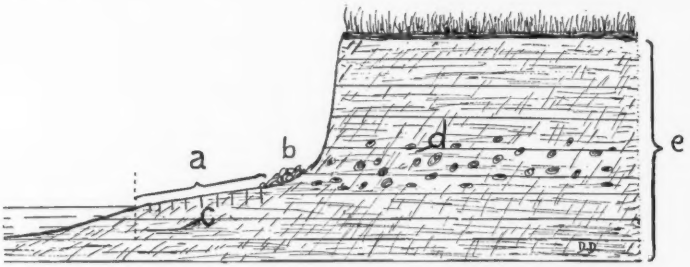

FIG. 1. Schematic cross-section of the Saint Lawrence bank in the Bellechasse Bay. The different zones relating to this subject are projected on a same plane. (a) Tidal zone.—(b) Littoral line where the rhizoconcretions are found.—(c) Concretions in formation.—(d) Pleistocene fossil bed.—(e) Gray-blue clay strata.

The author is indebted to Dr. W. H. Twenhofel, of the University of Wisconsin, Dr. E. M. Kindle, of the National Museum of Canada, Dr. Marie-Victorin, of the Institut botanique de l'Université de Montréal, Dr. Jules Labarre, of the department of Chemistry of the Université de Montréal, and M. Ubalde Baudry, for suggestions and help; to Mr. L. L. Russell and M. A. LaRocque, of the National Museum of Canada, who identified the Pleistocene fossils; to Mlle. D. Dubreuil, of

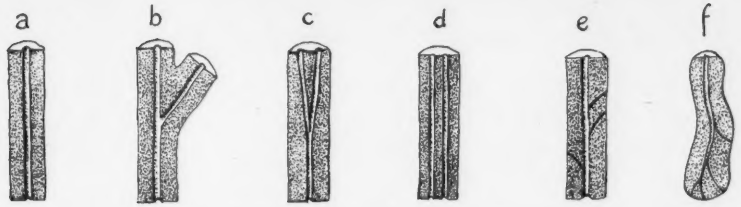

FIG. 2. Schematic cross-section of some rhizoconcretions.

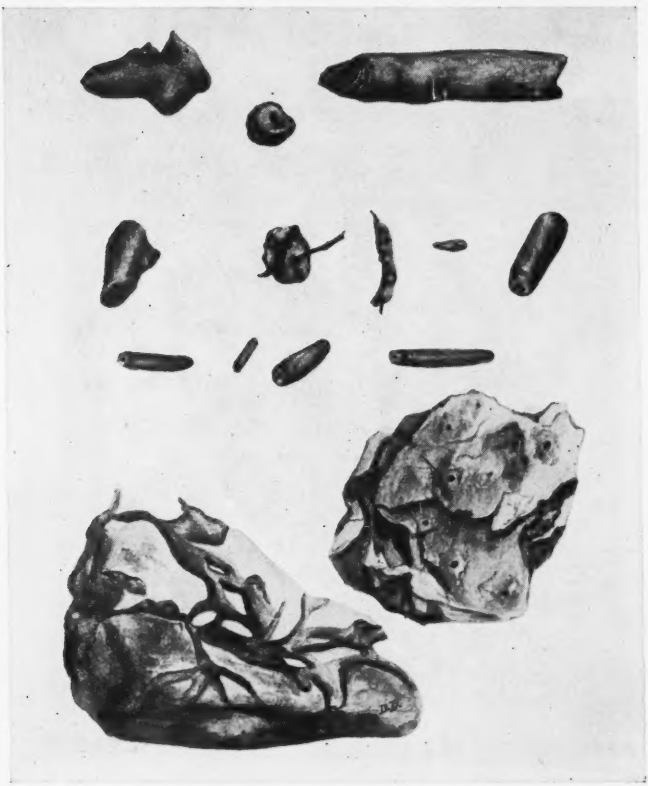

FIG. 3. Saint-Vallier rhizoconcretions. Above: Different kinds of rhizoconcretions; to be noted, two specimens in whose central cavity root remains are still found. Lower left: Granitic boulder covered by a branched concretion. Lower right: Fragment of clay where can be noticed a dark zone surrounding the cavity filled by the root.

the Institut botanique de l'Université de Montréal, for the accompanying illustrations.

DESCRIPTIONS OF THE CONCRETIONS

The concretions are mainly in the form of hollow cylinders, 5 to 75 mm. long and 2 to 15 mm. in diameter (fig. 3). The central lumen is 1 to 2 mm. in diameter (fig. 2a). Forked specimens occur rarely (fig. 2b); in some cases, however, only the central canal is forked and the bifurcation is not apparent externally (fig. 2c). Very rarely specimens have two canals, but externally the concretions are cylindrical (fig. 2d). Secondary canals extending from the central canal are often present. These are less than 0.2 mm. wide (figs. 2e and 2f). Many cylinders conceal root remains in their canals (fig. 3, center). The materials of the ochre-yellow concretions are of fine grain.

The origin of these concretions is obvious and the application to them of the name *rhizoconcretions*, suggested by Kindle,[1] seems fitting. Besides the standard form, a remarkable highly branched specimen was formed adhering to the surface of a granitic boulder (fig. 3, lower left). The whole specimen is about 15 cm. long.

AGE AND FORMATION OF SAINT-VALLIER RHIZOCONCRETIONS

The Pleistocene shells washed from the bank and mixed with rhizoconcretions are mainly *Hemithyris psittacea* (Linn.) (brachiopod); *Macoma calcarea* Chemnitz (pelecypod); *Neptunea despecta tornata* Gould and *Aporrhais occidentalis* Beck (gasteropods); and *Balanus* sp. (cirriped).

While surveying another part of the tidal shore, a few hundred feet down stream, a place was found where turf with a thickness of 15 cm. had been removed by ice and the underlying clay exposed. A number of black roots extended vertically downward into the clay. The still intact adjacent grassy turf permitted me to identify the roots as those of *Scirpus rufus* (Huds.) Schrad. (July 6, 1926, Rousseau 25190) and *Juncus balticus* Willd. var. *littoralis* Engelm. (Rousseau 25846).

The roots in the turf generally do not penetrate deeper than 15 cm. They radiate in all directions in the turf and thus form a close mat. Very few roots penetrate into the firm clay beneath and the adhesion of the mat thereto is so loose that moving ice can easily displace it and uncover the clay.

In the denuded areas, many roots of the underclay were found to be surrounded by an ochreous zone of clay (fig. 3, lower right, and fig. 4) having a radius of 1 to 2 mm. This clay forms the concretion. The fact that the ochreous clay is more compact than the ordinary clay permits concretions to be swept away by the tide.

The process giving rise to the Saint-Vallier rhizoconcretions may be summarized as follows:

1. The roots of *Juncus balticus* and *Scirpus rufus* penetrate clay underlying a surface mat of vegetation. The roots decay when the superficial mat is removed. The periodic covering of

[1] Kindle, E. M., Range and distribution of certain types of Canadian Pleistocene concretions: *Geol. Soc. America, Bull.*, vol. 34, pp. 609-648, 1923.

the beach twice each day and the alternate times of exposure to sunshine greatly hastens the decay of the root materials.

2. The gray-blue color of the clay encasing the roots, of which the color is due to iron sulphide, changes to the rusty color of iron oxide. This oxidation is thought to be favored by root decay. It does not seem to take place during the life of the plants as in no instance was an ochreous zone found surrounding living roots.

3. Oxidation leads to hardening of the clay.

4. The waves wash the hardened tubular concretions from the matrix and pile them on the litteral line where they generally resist weathering. Decay of the roots produces the central canal.

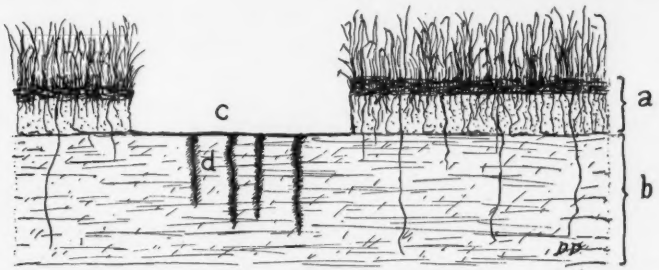

FIG. 4. Formation of the Saint-Vallier rhizoconcretions. (a) Muddy superficial mat.—(b) Pleistocene clay strata pierced by some roots.—(c) Zone cleared by the ice.—(d) Formation of ochreous concretions around the roots.

NOMENCLATURE

The actual formation of rhizoconcretions does not seem to have been previously observed and consideration has been given to Pleistocene and older rhizoconcretions already formed. A concretion characterized by centrifugal growth proceeding from the inside to the outside was named *accretion* by Todd;[2] the reverse centripetal type growing from the outside to the inside was termed *incretion*. The Saint-Vallier concretions are neither accretions nor incretions as they form from chemical changes taking place in the material of which they are composed. They would be termed *rhizomorphs*[3] by Hill and *rhizoconcretions* by Kindle.[4] The latter name seems the more appropriate.

From the point of view of relative age, using Tarr's classification,[5] the Saint-Vallier concretions are *epigenetic*. Richardson[6] considers three divisions in the relative age of concretions. The contemporaneous concretions "grew on the sea-floor at the same

[2] Todd, J. E., Concretions and their geological effects: *Geol. Soc. America, Bull.*, vol. 14, pp. 353-360, 1903.

[3] Hill, William, Flint and chert: *Geol. Assoc., Proc.*, vol. 22, pp. 61-94, 1911.

[4] Kindle, E. M., op. cit.

[5] Tarr, W. A., Syngenetic origin of concretions in shale: *Bull., Geol. Soc. America*, vol. 32, pp. 373-384, 1921.

[6] Richardson, W. A., The relative age of concretions: *Geol. Mag.*, vol. 58, pp. 114-124, 1921.

time, and at about the same rate as the surrounding deposit was laid down." The *penecontemporaneous concretions* "segregated more or less close to the surface of recently deposited sediment." The *subsequent concretions* "formed after deposition had finished and after the strata had largely consolidated, but perhaps before cementation had taken place to any noteworthy extent." The Saint-Vallier concretions may be considered penecontemporaneous as they formed close to the surface of unconsolidated deposits. They owe their structure to the oxidation of clay under the influence of a central nucleus, the root in the present case.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 2, PP. 65–77, FIGS. 1–4,
AUGUST, 1934

SIZE FREQUENCY DISTRIBUTIONS OF SEDIMENTS

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ABSTRACT

Distinction is made between continuous and discontinuous variables in frequency distributions. Histograms, frequency curves, and cumulative curves are discussed in relation to each other. On the basis of these relations an attempt is made to explain why histograms vary with the grade scale used in mechanical analysis, while cumulative curves do not. The disadvantages of histograms may be avoided by a simple graphic method for obtaining a continuous frequency curve independent of the grade scale. This curve is obtained by graphic differentiation of the cumulative curve, and is expressed in terms of the Wentworth descriptive grade scale. The analytic scale for obtaining the data is, however, shown to be independent of the descriptive scale units. It is suggested that in analyzing sediments, as many points as necessary be determined along the cumulative curve, to reduce errors of smoothing to a minimum.

CUMULATIVE CURVES AND FREQUENCY CURVES

It has long been recognized that frequency pyramids or histograms[1] of sediments vary in shape according to the grade scale used in mechanical analysis.[2] It is evident that a given sample can have only one unique frequency curve and a corresponding unique cumulative curve. There must, accordingly, be an assignable reason for the variability of histograms, but to the writer's knowledge no attempt has been made to explain this phenomenon.

It is the purpose of the present paper to attempt an explanation of why histograms vary in shape while cumulative curves do not, and to indicate a simple graphic method for obtaining the unique frequency curve from the cumulative curve. The implications of the data presented, in terms of possible modifications in the technique of mechanical analysis, will also be pointed out.

In statistical nomenclature, frequency distributions are defined as continuous when the variable being

[1] The term "histogram" appears to have been discarded in favor of "frequency pyramid" by some workers in mechanical analysis. The former word is in good repute among statisticians, and is accepted by H. L. Rietz (*Handbook of mathematical statistics,* Boston, 1924, p. 22), by F. C. Mills (*Statistical methods,* New York, 1924, p. 76), and by several other writers consulted. The greater convenience of the word "histogram," and its widespread acceptance, incline the writer to its use.

[2] Dake, C. L., The problem of the St. Peter sandstone: *Univ. Missouri, School of Mines and Met., Bull.,* vol. 6, pp. 173 ff., 1921. Wentworth, C. K., Methods of mechanical analysis of sediments: *Univ. Iowa, Studies in Nat. Hist.,* vol. 11, no. 11, pp. 46 ff., 1926. Rubey, W. W., Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: *U. S. Geol. Survey, Prof. Paper 165A,* p. 22, 1930. Galliher, E. W., Cumulative curves and histograms: *Am. Jour. Sci.,* vol. 26, pp. 475-478, 1933. Dryden (*Am. Jour. Sci.,* vol. 27, p. 146, 1934) recently criticised Galliher's views, but his criticism appeared after the present paper was written.

measured differs by infinitesimals along its range, and as discrete when the variable differs by finite amounts, with no gradation to the next value.[3] Thus the heights of men may be used as an example of the former, and a collection of coins the latter. In mechanical analysis the independent variable is the diameter of the particles, expressed as "equivalent radii" or as settling velocities. From the nature of the particles composing sediments it is clear that, with few exceptions, the diameters vary by infinitesimals along the entire range of sizes represented, rather than by abrupt steps from one size to the next.

In continuous distributions smooth curves best represent the continuous gradation in size.[4] Thus in such distributions the concept of a definite class interval is absent. In studying these distributions, however, convenient units are desirable, but the units themselves are quite arbitrary. Usually the class interval is determined by the nature of the data, and by the number of classes best adapted to furnish a smooth frequency curve. This arbitrary nature of the class interval used in the analysis of continuous distributions should clearly be recognized.

In analyzing any continuous distributions, statisticians recommend the use of equal class intervals, but where the nature of the data makes this inconvenient or impossible, unequal intervals may be used.[5] The wide range of sizes among sediments renders it generally impossible to use equal intervals without introducing an indefinitely large number of very small classes. For the same reason, the diameters are usually plotted on a logarithmic scale, and here again the choice is immaterial, providing due cognizance is taken of the change in the shape of the curve introduced by transformation to a logarithmic scale.

When the class intervals are equal, the frequency curve may be obtained directly from the histogram by choosing smaller and smaller units, and finally drawing a smoothed curve through the histogram bars, in such a manner that the area under the curve is preserved. To maintain the area constant, it is necessary to double the scale along the Y-axis every time the class interval is halved. In effect, then, the frequency curve is a picture of the distribution when the class interval has been reduced to zero, and the number of individuals increases without bound. Both frequency curves and histograms have the important characteristic that they are *areal* representations of the frequency, the total *area* under the curve being 100 per cent.[6] A single ordinate in both cases is relatively meaningless[7] because an area under the curve requires an interval along the X-axis as well as the height of an ordinate. In histograms these intervals are

[3] Rietz, *op. cit.*, p. 20.
[4] Mills, *op. cit.*, p. 81.
[5] Karsten, K. G., *Charts and graphs*, New York, 1925, p. 320.
[6] Rietz, *op. cit.*, pp. 22-23.
[7] A single ordinate of the frequency curve measures the rate of change of frequency per unit along the X-axis, and is thus in the nature of an abstraction rather than a directly usable value. It is conceivable that this rate of change could be used to characterize parts of the curve, if some suitable name were applied to it, just as velocity, which is the rate of change of distance with respect to time, has considerable significance in physics.

fixed by the grade scale, but in frequency curves any two points along the X-axis may be chosen, and the area under the curve between the two corresponding ordinates computed or estimated.

It appears to be generally agreed among statisticians that a smooth frequency curve is more suitable for continuous distributions because it emphasizes the continuous variation in size, while a histogram implies a discrete series in the sharp break between the classes. Further, the proportion of material in any size range may be determined from the frequency curve, while in histograms the areal relations are confined to the particular class intervals chosen. Thus the frequency curve is a generalization of the histogram, and is to be preferred for continuous data.

The above discussion shows a close relation between histograms and frequency curves. There also exists a relation between frequency curves and cumulative curves, and to demonstrate this relation, an important characteristic of curves in general must be discussed. By the calculus it may be demonstrated that every continuous curve has associated with it an integral curve and a derivative curve. The integral curve is such that its ordinate at any point represents the *area* under the given curve up to that point, while the derivative curve is such that its ordinate at any point represents the *slope* of the given curve at that point. Now the relation is also such that if one curve is the integral of a second curve, the second curve is itself the derivative of the first. Hence when two curves bear these relations to each other, the ordinates of the integral curve may be used to represent areas under the derivative curve, and the ordinates of the derivative curve in turn may be used to represent the slope of the integral curve.

It is a widely recognized fact that a cumulative curve is the integral of its corresponding frequency curve, and consequently that the frequency curve is the derivative of the cumulative curve. This may be demonstrated briefly as follows: When a cumulative curve is prepared from a histogram, the per cent of material in each class is summed to obtain the successive ordinates of the cumulative curve. Thus the ordinates of the cumulative curve are linear representations of the *area* under the histogram up to that point. Further, the total area under the histogram is the sum of the areas in the successive blocks. But by the calculus, the limit of such a sum, as the intervals become smaller and smaller, is the integral of the function taken over the range involved.[8] Thus the cumulative curve is the integral of the frequency curve, and conversely, the frequency curve is the derivative of the cumulative curve.

It will be recalled that the area under the histogram or frequency curve represents the total percentage of grains in the distribution. The fact that the cumulative curve is the integral of

[8] If the class interval is Δx, the ordinate of the frequency function $f(x)$, and the range of sizes from a to b, then by the fundamental theorem of the integral calculus, described in every text on the subject, we have:

$$\lim_{\Delta x \to 0} \sum_{i=1}^{n} f(x_i)\Delta x_i = \int_a^b f(x)dx.$$

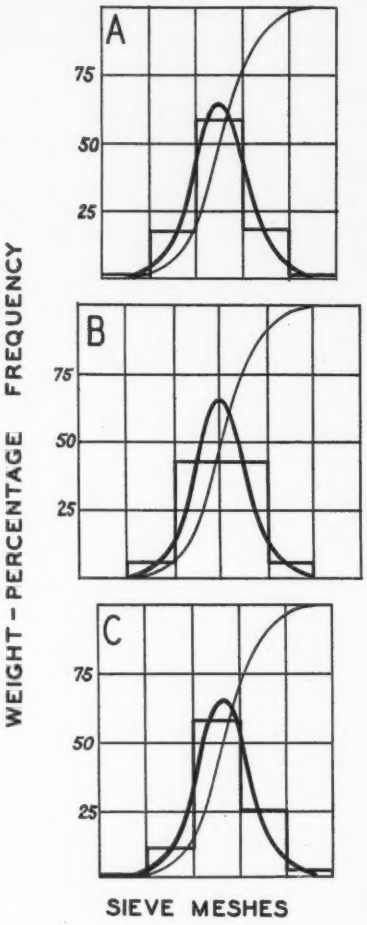

FIG. 1.

the frequency curve explains why a single ordinate of the cumulative curve enables us to read the total percentage of grains greater or smaller than that particular diameter, and the difference of two ordinates yields the per cent of material between the two corresponding values of the diameter. Similarly, it explains why the frequency curve reaches its greatest height where the slope of the cumulative curve is greatest.

THE VARIABILITY OF HISTOGRAMS

In making a mechanical analysis with a fixed grade scale, a particular histogram is obtained which represents the actual distribution of grains in terms of the grade scale used, and it is thus strictly a picture of the facts. However, these facts, in that form, may tell us very little about the frequency distribution considered as a continuous function of the diameter. In setting up a histogram, we are in effect setting up a series of separate "bins," each of which contains a certain per cent of the grains. If the "bins" are changed, the percentages change, and who can tell by inspection whether we have the proper "bins" in a given case to bring out most clearly the nature of the distribution?

A purely fictitious picture of a sediment may be obtained by the use of histograms based on particular grade scales. It is evident that in any given case it is purely accidental where the fixed grade scale will intersect the frequency curve. In figure 1 three cases are shown, in which the separate grade scales all have geometric intervals, but different grade limits. The same sediment will then be distributed over the sieves according to the manner in which the scales intersect its frequency curve. In *A* it is postulated that the mode of the frequency curve falls exactly half way between two grade

limits, which here represent the logarithms of the sieve sizes used. The corresponding histogram and cumulative curve resulting from the analysis are shown. In this case the modal group is preserved on a single sieve, and the resulting histogram is an excellent portrayal of the frequency curve. In *B*, on the other hand, the mode is considered as falling exactly on one of the class limits. Here the modal group is split equally between two sieves, and the resulting histogram is still symmetrical, but does not show the concentration in the modal group. The cumulative curve, however, is the same as before. In *C* the mode falls closer to one class limit than to the other, and the histogram is found to be definitely skewed, because the modal group is unequally divided between the two sieves. Again the cumulative curve is the same as before, but one would conclude from the histogram alone that the sample represented a distinctly different type of sediment.

Thus practically any shaped histogram may be obtained from a given frequency curve, depending on the accidental intersection of the curve by the grade limits. Two general situations may be read from figure 1. Either the sediment may be considered constant, and the three scales slightly different, as shown, or the grade scale may be considered fixed in the three cases, with a very slight change in the sediment. In either case there seems to be no way of determining from the histograms alone which is the correct picture. Since the chances are about equal for such accidental intersections in any fixed grade scale, it is clear that no single scale can be advanced as the one furnishing the "correct" histograms in every case. In fact, the logical conclusion is that such histograms are of little value in interpreting the nature of the sediment.

It is now pertinent to consider why the cumulative curve remains the same, while the histograms vary. It was mentioned above that the cumulative curve is the integral of the frequency curve. Now in cumulating the sieve data, a process of finite integration is performed, which converts the finite intervals into a continuous function when the curve is smoothed. The histograms, on the other hand, are plotted as "raw" data, and so preserve the accidents of treating the continuous function as a series of relatively finite intervals.

This discussion demonstrates that histograms prepared on any of the commonly used grade scales are not reliable as bases for interpreting the nature of sediments. Instead, they are mere approximations to the frequency curve, and are subject to the large errors that may be introduced by the fortuitous relations of the frequency curve to the fixed grade scale. Cumulative curves, on the other hand, are not subject to this influence to the same degree, and consequently are more reliable as indices to the nature of the distribution.

Despite the greater reliability of cumulative curves, it has been felt by numerous workers that the histogram type of presentation has certain advantages over the cumulative curve.

Small variations in frequency may more readily be visualized, and modes can more easily be seen than inflection points. It would therefore be advantageous if a unique frequency curve could be obtained from the data, independent of the grade scale in the same way that the cumulative curve is independent of it.

Much of the confusion incident to mechanical analysis has arisen from a failure to distinguish between two separate functions of grade scales. It was pointed out earlier that a grade scale of some kind was necessary for analyzing a sediment, so that the data may be treated as convenient units along a continuous curve. In addition to this analytic use there is a purely descriptive function served by grade scales. It is quite necessary that some standard grade scale be available for describing sediments in terms of their contents of gravel, sand, silt, and clay, and the particular units chosen for this purpose need no other justification than that they are of mutual agreement. The Wentworth scale,[9] as such a descriptive device, has gained widespread recognition, and admirably serves this descriptive function.

Confusion was introduced into the picture, however, by the variability of the histograms drawn from the sieve data. In order to compare the figures directly, it was necessary that all analyses be made by this same grade scale. As a matter of fact, there is no necessary relation between the two functions of the grade scale, and to insist that analyses be conducted by the descriptive scale is to set definite limits on the reliability of the data secured from the analysis. No such limitation is necessary; the unique frequency curve may be expressed in terms of the descriptive scale regardless of the particular scale used in the analysis.

[9] Wentworth, C. K., A scale of grade and class terms for clastic sediments: *Jour. Geology*, vol. 30, pp. 377-392, 1922.

GRAPHIC DIFFERENTIATION OF CUMULATIVE CURVES

There are several methods by which an approximation to the unique frequency curve may be obtained from sieve data. One such is obtained by drawing a smooth curve over the histogram itself, if care be exercised to preserve areas in the smoothing process. A method of numerical computation of the ordinates of the frequency curve, on an equal class-interval basis, is also available and has been described by Van Orstrand.[10] There is, however, a simple method of obtaining the frequency curve directly from the cumulative curve by a graphic method, the technique of which will be described here. Since the frequency curve is the derivative of the cumulative curve, the usual method of graphic differentiation may be used, but cognizance should be taken of the fact that the X-axis is logarithmic. Further reference to this point will be made later.

[10] Van Orstrand, C. E., Note on the representation of the distribution of grains in sands: Researches in sedimentation in 1924, *Nat. Research Council*, pp. 63-67, 1925. See also Odén, S., On clays as disperse systems: *Trans. Faraday Soc.*, vol. 17, p. 327, 1921-22; and Jennings, D. S., Thomas, M. D., and Gardner, W., A new method of mechanical analysis of soils: *Soil Sci.*, vol. 14, p. 485, 1922, for other graphic methods.

Before graphically differentiating the cumulative curve, certain conventions should be adopted, so that the frequency curve is obtained in terms of a descriptive grade scale. The writer follows the practice of using 3-cycle semi-logarithmic paper (Eugene Dietzgen #340-L310), in which the length of a cycle is about 8.1 cm., so that when the Wentworth scale is laid off along the X-axis, the actual distance between successive points is about 2.4 cm. Also by convention, 10 per cent on the vertical scale is chosen so that it is about half the length of the horizontal scale unit, or about 1.2 cm. This assures a cumulative curve which is usually not too steep for convenient handling. By adopting these conventions the final curves are directly comparable, because they are all obtained in reference to fixed scale relations.

When the variables are plotted on arithmetic scales a pole P is usually drawn to the left of the vertical axis at a distance equal to a unit along the X-axis. By this means the ordinates of both the cumulative curve and frequency curve may be read from the same numerical units of the Y-axis. Proof of the relations between the pole distance and the scale units in the arithmetic case are available in references.[11] In the present case a logarith-

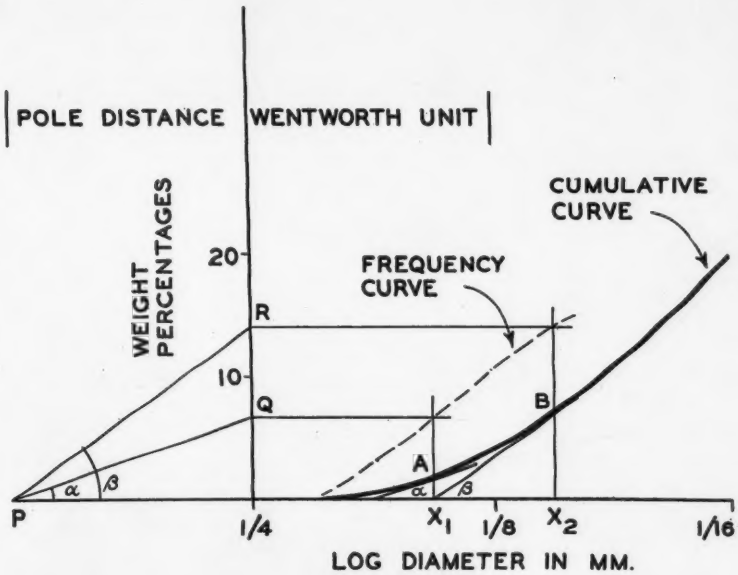

FIG. 2

[11] Von Sanden, H., *Practical mathematical analysis*. Translated by H. Levy. New York, 1924, Chap. VII.

mic X-scale is used, but fortunately the same relations hold as in the arithmetic case,[12] and the pole P is drawn to the left of the vertical axis a distance equal to the arithmetic value of the Wentworth units along the X-axis, here 2.4 cm. Since in such logarithmic scales the geometric ratio between successive points yields equal arithmetic intervals, the length of the interval determines the pole distance. In figure 2 a cumulative curve is shown in part, to illustrate the arrangement.

It will be noted that the diameters laid off along the X-axis decrease to the right. This accords with usual sedimentary practice, but is the reverse of general mathematical practice. The writer was formerly of the opinion that standard mathematical practice should be followed, but further consideration points to the advisability of adopting the convention shown here. Reasons that may be cited are that the analytical data are obtained in the order shown, from the larger diameters to the smaller; most sediments have the bulk of their grains smaller than 1 mm., and their logs to any base will be positive numbers in the present convention; finally, this convention co-ordinates cumulative and frequency curves obtained by any method with those obtained from Odén curves, which are plotted in the same sense. A similar case is found in the plotting of stellar magnitudes in astronomy, so that the convention is no radical departure from accepted practices.

The cumulative curve is divided into any convenient number of units, and at each of the points an ordinate is erected to the curve, as at x_1A, x_2B. These ordinates need not necessarily coincide with the experimentally determined points of the cumulative curve. A tangent is now drawn to the cumulative curve at A. The angle α, made by this tangent with the horizontal, is then laid off at P, and the line PQ is drawn. From Q, where the ray of the angle intersects the Y-axis, a horizontal line is drawn to the ordinate x_1A or its projection. The intersection of the horizontal line from Q with this ordinate locates a point on the desired frequency curve. The process is repeated at x_2B, where the tangent at B makes an angle β with the horizontal. When this angle is laid off at P, it yields the point R on the Y-axis, and finally the second point along the frequency curve. Further repetition yields as many points on the frequency curve as the number of originally chosen points along the cumulative curve. In general, these arbitrarily chosen points of tangency may not include the inflection point[13] of the cumulative curve. Hence a separate determination should be made at that point because the mode of the frequency curve lies on the ordinate of the inflection point.

In choosing intervals along the cumulative curve, it is well to include at least ten, and when the form of the frequency curve develops, additional points may be chosen to bring out needed details. It should be recalled that both curves represent continuous

[12] A theoretical proof of the validity of the method with logarithmic X-scales may be found in the appendix at the end of the present paper.

[13] The inflection point of a curve is the point of maximum slope of the tangent. It is the point where the tangent to the curve changes its direction of rotation. It may accordingly be located by moving a ruler along the curve so that it is always tangent to it, until the point is reached where the direction of rotation of the ruler reverses itself.

functions, and consequently one is not limited to specific points along either curve. The possible errors introduced by the smoothing process will be discussed below.

Figure 3 is inserted to illustrate several types of frequency curves obtained by the method described, and it shows as well the corresponding cumulative curves. Certain points may be noted. In curve *A*, which represents a beach sand, the highest ordinate of the frequency curve extends above the 100-per cent line of the cumulative curve. This means that the steepness of the cumulative curve at that point is so great that the rate of change of per cent per unit of the grade scale here is 105 per cent. In other words, the grains are very highly concentrated about this modal value.

Curve *B* of figure 3 represents a loess, in which the cumulative curve is less steeply inclined, so that the mode of the frequency curve is much less accentuated than in the sand. Curve *C* represents a glacial till, in which more than one mode occurs, and is an example of a polymodal frequency curve.

These examples focus interest on another point, which is the accuracy of the graphic method. It may confidently be stated that if the curvature of the cumulative curve is known at every point, and if the tangents are correctly drawn, the method yields rigorous results. In experimental work, however, interpolation of the cumulative curve is necessary, and to the extent that the smoothing introduces errors, the final results are inaccurate. Also the tangents to the curve cannot be drawn correctly by inspection, and another error is introduced by this fact. There are devices for reading the tangents to curves,[14] and hence this error may be made practically negligible. The correction of the error involved in smoothing the cumulative curve requires some discussion.

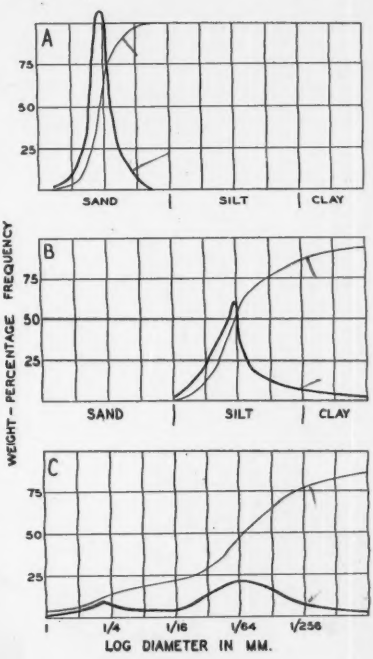

FIG. 3

As stated earlier, cumulative curves are independent of the grade scale used in the analysis, but in smoothing such curves it is obvious that the precise locations of the known points will influence the smoothing process, so that

[14] The Richards-Roope tangentmeter, offered by Bausch & Lomb, is such a device.

the cumulative curves obtained from different grade scales may not be completely identical, especially if too few points are known. Since both cumulative curves and frequency curves of sediments are continuous functions of the diameters, the most logical way of avoiding these errors of smoothing is to determine by experiment as many points as possible along the cumulative curve. It should be borne in mind that uneven class intervals do not distort the cumulative curve, and consequently as many points may be experimentally determined as one wishes, regardless of the particular intervals between successive points. It is not feasible, however, to construct a histogram from such unequally spaced points, unless the points have a fixed ratio to each other. Thus in using the analytic data to construct a cumulative curve, one is independent of the need of a fixed scale for analysis.

The average cumulative curve consists of a steep middle portion bounded by two less steep parts, so that in general it is a sigmoid.[15] Inasmuch as the main body of the sediment is contained in the steep part of the curve, it is here that the most detailed study should be made. Many workers are familiar with the fact that in some sediments more than 60 per cent falls within a single grade of the usual scale used in mechanical analysis. It is obvious that any smoothing across such a steep curve will be subject to serious errors. It would be preferable, perhaps, to have no more than 5 or 10 per cent of the sediment between any two points along the cumulative curve, and this means that in the steep part of the curve a number of additional points may well be determined. Among fine-grained sediments, where one of the modern continuous methods of analysis may be used, as many points may be determined as wished. With coarser sediments one is limited by the number of sieves available over the range involved. Even here, however, satisfactorily small intervals may often be had. One manufacturer alone[16] offers 29 sieves for the range from 1 mm. to 0.1 mm., and 10 sieves from 0.1 mm. to 0.43 mm. When it is considered that the Wentworth scale offers only 5 sieves over this entire range, and the scale based on $\sqrt{2}$ offers only 10, the possibilities for detailed analyses become at once apparent.

From what has been said, it is clear that no fixed grade scale of any kind is necessary for locating points along the cumulative curve. On the contrary, any desired degree of accuracy may be had, limited only by the experimental errors and the apparatus available. In fact, it is a matter of judgment where the most detailed analysis need be made, and in general it may be said that attention should be focused on the steep part of the cumulative curve, in an attempt to locate the inflection point or points as accurately as possible.

Despite the distribution of the known points along the cumulative curve, the convention suggested earlier of using the Wentworth scale as the

[15] Robinson, G. W., The form of mechanical composition curves of soils, clays, and other granular substances: *Jour. Agric. Sci.*, vol. 14, pp. 626-633, 1924.

[16] The W. S. Tyler Company, Cleveland, Ohio. *Catalogue 53*, 1930.

fundamental divisions along the X-axis at once ties together the analytic and descriptive features of the curves. When the cumulative curve is differentiated, the frequency curve is located in terms of the descriptive grade scale and the relative amounts of sand, gravel, etc., may be directly estimated from the shape of the curve, or measured more precisely by contrasts of areas.

SUMMARY

It has been emphasized that a relatively high degree of accuracy is available for determining the unique frequency curve of a sediment. Some workers will feel, however, that the errors of sampling, of laboratory technique, and the like, are themselves so large that any great accuracy in the graphic method is offset by the errors in the data. The writer himself inclines in part toward this opinion, but he is convinced that even if no more points are determined along the cumulative curve than is now the custom, the frequency curve obtained by the graphic method will be a more reliable index to the nature of the sediment than the usual histograms, which cannot be relied upon with certainty in any case.

The main point the writer wishes to emphasize is that the grade scale used in the analysis is not necessarily related to the final descriptive scale, so that workers may confidently determine any convenient points along the cumulative curve, and by the method described arrive at an approximation of the unique frequency curve which is comparable with curves obtained from other experimentally determined points along the original cumulative curve. In short, it may be left to the judgment of the analyst to decide how accurate his results should be for the problem at hand. If the experimentally determined points are given, the relative dependability of the smoothing may be recognized at once by others to whom the results are presented.

The writer is of the opinion that cumulative curves are sufficient for all ordinary purposes in routine analyses, because the medians, quartiles, and other pertinent data for comparisons may be simply obtained from them. It is often convenient, however, to contrast a series of frequency curves to bring out variations in range, in the degree of sorting, or in successive positions of the mode from sample to sample. In such cases the frequency curves obtained by graphic differentiation are much superior to the accidental forms of histograms, which so obviously depend on the scale used in the analysis.

Further, in complex distributions where more than one mode occurs, it is desirable to have some means of estimating the nature of the several individual frequency distributions that make up the composite curve. Here then the determination of the frequency curve affords data which may be made the basis of a statistical method of comparison.

It may be mentioned in passing that the graphic method of differentiation is applicable not only to curves based on weight percentages, but also to the study of similar curves obtained from analyses by count, by volume, or by degree of roundness and the like.

APPENDIX

No references were found by the writer to the graphic differentiation of curves with a logarithmic X-scale, and the following theoretical proof is submitted of the applicability of the method in such cases. The writer is indebted to Dr. C. Eckart of the Department of Physics of the University of Chicago for the details of approach, as well as for much helpful advice and criticism of the paper in general.

In the conventions adopted, it is possible to plot directly the values of the experimentally determined points of the cumulative curve in terms of their logs to the base 10. At the same time, the Wentworth units determine the areal relations of the resulting frequency curve by fixing the position of the pole P. For plotting purposes we may lay off the logs of the Wentworth scale to the base 10, in which case the distance between successive points will be $k \log_{10}2$, where k is the length of a logarithmic cycle on the graph paper. If the convention of decreasing the values of ξ to the right is followed, the choice for plotting is $x=-k \log_{10}\xi$, where x is the actual distance along the X-axis from the arbitrary origin $\log_{10}1=0$, k is the length of a cycle, and ξ is the numerical value of the diameter.

The transformation $\log_{10}\xi=\log_{10}2 \log_2\xi$ may be used to locate the pole P in terms of the Wentworth scale. Substitution in the equation for x yields $x=-k \log_{10}2 \log_2\xi$. Call the unit along the X-axis λ_x, and set $k \log_{10}2=\lambda_x$. Now let $\phi=-\log_2\xi$, and by substitution we have

$$x=\lambda_x\phi \quad \ldots\ldots\ldots\ldots (1)$$

The substitution $\phi=-\log_2 \xi$, or $\xi=(\frac{1}{2})^\phi$, is made in part for typographical convenience, but also to introduce a convenient symbol that may be used for expressing grain diameters in terms of Wentworth units. Here ϕ may be called the *Wentworth modulus* or *Wentworth exponent*, and may be used directly in computations involving grain sizes. With values of ξ equal to 2, 1, $\frac{1}{2}$, $\frac{1}{4}$, ϕ equals $-1, 0, +1, +2$, respectively. Thus ϕ increases with decreasing diameter, and the Wentworth scale becomes arithmetic, with $\phi=0$, ($\xi=1$ mm.) as the origin. It is possible to interpolate arithmetically on this scale, and to express grain diameters in ϕ-terms directly. To obtain actual diameters, ϕ may be transformed to ξ logarithmically.

We may next choose y and y', the actual heights of the ordinates of the cumulative and frequency curves respectively, such that

$$y=\lambda_y\eta \quad \ldots\ldots\ldots\ldots (2)$$
$$y'=\lambda_y\zeta \quad \ldots\ldots\ldots\ldots (3)$$

where η is a function of ϕ, and λ_y is the unit along the Y-axis, chosen equal in both cases so that the same numerical unit applies to the ordinates of each curve.

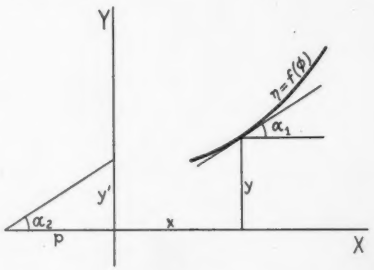

FIG. 4

From these parametric equations we let $\eta=f(\phi)$ be the cumulative curve, so that $\zeta=d\eta/d\phi$ will be the corresponding frequency curve. In figure 4 a tangent is drawn to the cumulative curve at y, making an angle α_1 with the horizontal. By the calculus we have $\tan \alpha_1=dy/dx$, and from equation (2),

$$\tan \alpha_1=dy/dx=\lambda_y \, d\eta/dx=\lambda_y \frac{d\eta}{d\phi}\frac{d\phi}{dx} \quad \ldots (4)$$

But $d\eta/d\phi=\zeta$, and from equation (1), $dx/d\phi=\lambda_x$, so that $d\phi/dx=1/\lambda_x$. Substituting in equation (4) we obtain

$$\tan \alpha_1 = \frac{\lambda_y \zeta}{\lambda_x} \quad \ldots\ldots\ldots (5)$$

Also from figure 4, $\tan \alpha_2 = y'/p$, where p is the pole distance. From equation (3), $y' = \lambda_y \zeta$, and by substitution we have

$$\tan \alpha_2 = \frac{\lambda_y \zeta}{p} \quad \ldots\ldots\ldots (6)$$

But by construction in the graphic method, $\alpha_1 = \alpha_2$. Hence we may equate (5) and (6):

$$\frac{\lambda_y \zeta}{p} = \frac{\lambda_y \zeta}{\lambda_x}$$

from which we obtain

$$p = \lambda_x$$

and the method applies.

In the present case $k = 8.1$ cm., $\log_{10} 2 = 0.301$, so that $\lambda_x = p = 2.4$ cm., and the pole distance is equal to the distance between the Wentworth units along the X-axis.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 2, PP. 78–81, FIG. 1,
AUGUST, 1934

METEOROLOGY OF THE DUSTFALL OF NOVEMBER 12-13, 1933

ERIC R. MILLER
U. S. Weather Bureau, Madison, Wisconsin

ABSTRACT

A cyclonic storm of the "Alberta" type, moving eastward along the Canadian border was accompanied by gales of extraordinary violence in the Missouri valley on Sunday, November 12, 1933. Day-time turbulence carried immense quantities of dust into the air. The diverging cold-air-mass following the storm center carried the dust cloud to the Appalachian and Gulf states by the morning of the 13th, after which it was lost sight of in mists and light rain in the mountains, and by dispersion elsewhere.

Dr. A. E. Alexander, whose paper on the atmospheric dust precipitated at Buffalo, New York, appears in this JOURNAL, asked me to discuss the meteorological aspects of the dustfall.

Meteorological observations are now so numerous, on account of the development of the weather service along the commercial airways, and the addition of upper air observations with pilot balloons and airplanes, that it is possible to fix the origin of the Buffalo dustfall of November 13, 1933, with a high approach to certainty. The region of "deflation" is shown by closed ovals on figure 1. Within this region the winds were light to moderate in the early morning of November 12, 1933, but increased steadily, so that by 1:30 P.M. fierce gales with velocities of 45 to 63 miles per hour were raging over a wide area from Bismarck, North Dakota, to Kansas City, Missouri, and from the Badlands of South Dakota, and the Sand Hills of Nebraska to the Mississippi River.

The strength of the wind was so great that not only dust but gravel and pebbles whirled up from the roads, fall-plowed fields were obscured by clouds of drifting soil, large branches were torn from trees, electric power lines were blown down, and roofs torn off. The dust was so thick that objects 50 to 100 feet away could not be seen. The dust entered houses through crevices, and covered furniture, clothing, etc., even in closets, so that thorough house-cleaning was necessary.

The cause of this disturbance was one of a dozen cyclonic storms of the "Alberta" type that moved along the Canadian border during November, 1933. The track of the center is shown on figure 1. At 8 A.M., November 12, the center passed near Winnipeg, where the lowest pressure was 29.32 inches. The blowing of dust did not begin until after the wind shifted to northwest, but examination of the detailed weather maps prepared from the airway meteorological reports, indicates that it was not in the cold-air

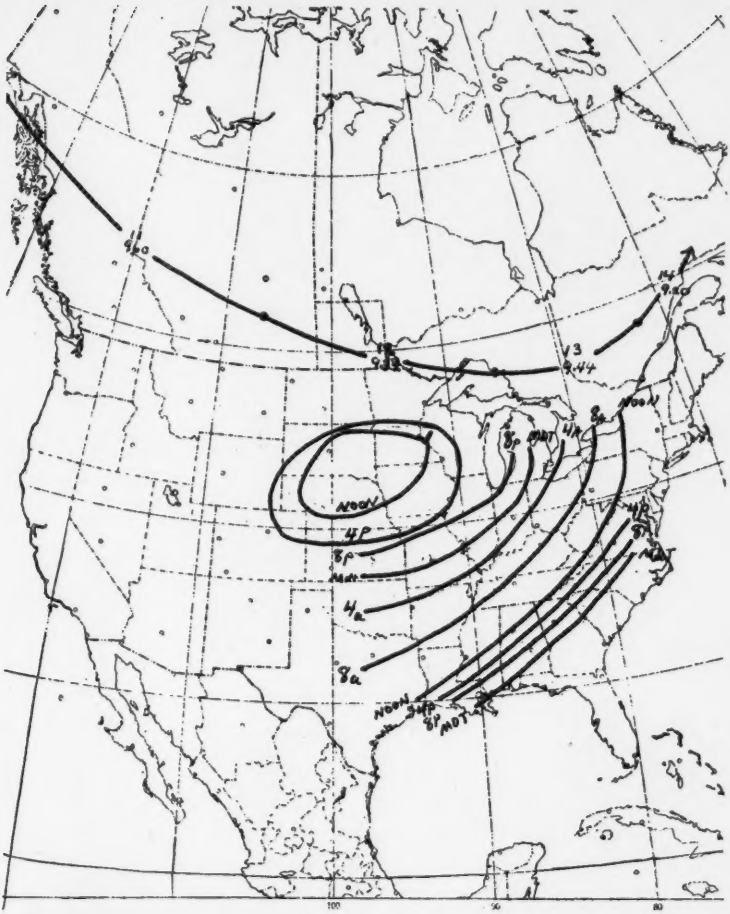

FIG. 1. Track of center of cyclonic storm (above) and isochrones showing progress of dust-cloud from noon, Nov. 12, 1933 to midnight, Nov. 13, 1933.

mass that followed the storm from the snow covered plains of northern Canada, but in Chinook winds, warmed by descent from the plateau region west of the Rocky Mountains, that the dust-storm occurred.

The reports of the airways observers at Pueblo, Denver, Cheyenne, and Sheridan, show extraordinarily low relative humidities early in the morning of the 12th. The greatest dryness, however, did not occur at the foot of the mountains where it would naturally be expected, if due to Chinook conditions,

but at Kansas City, where 10 per cent was recorded at 8 P.M. of the 12th. This fact hints that subsidence and heating by compression continued as the air mass diverged to fill the area between the mountains and the retreating warm air-mass east of the wind-shift line that moved eastward with the storm center.

The dust-cloud was carried mostly southeastward by the storm winds, but with much spreading toward the north and west. The hourly reports by teletypewriter along the airways enable the progress of the dust cloud to be followed through the afternoon and night of the 12th and in the southeastern states on through the whole of the 13th. Isochrones for every fourth hour, figure 1, show the advance of the front of the dust cloud. In Tennessee, northern Alabama, and Georgia, the density of the dust cloud was such that the horizontal visibility was reduced to a mile or less (one-fifth of a mile at Chattanooga at noon, November 13). The western and northern wings were markedly thinner. At Dallas, Texas, the meteorological airplane flight at 5 A.M., E.S.T., November 13, rose throgh a stratum of dusty air, 5,500 feet thick before emerging into clear air above. The airways observer at Buffalo, New York, at 10:02 A.M., E.S.T., reported "Dark in northwest, thick dust approaching from west," while at Mercer, Pennsylvania, the visibility was reduced to one mile by the dust at 9:42 A.M. Jamestown, New York, reported dust in rain about 9 A.M. At Rochester, New York, housewives complained to the newspapers of muddy rain on their Monday washings hung out to dry. At Syracuse, rain-precipitated dust was afterward found on windows and automobiles, and the airways observers at Bellefonte, Pennsylvania, observed dust with mist and rain between 3:15 and 4:35 P.M. At Watertown, New York, the dust-cloud itself was observed at 3:30 P.M. At Binghamton, there was no rain to precipitate the dust, and none was found on the control air-filters of the paper factory of the Agfa Ansco Corporation. At Alexandria Bay, New York, the observer noted discolored rain falling at 2 P.M. In Vermont the phenomenon escaped the attention of the professional observers, but these received inquiries from the eastern part of the state about "brown snow."

Wind-borne dusts are of interest to geologists for the light that they throw on the rate of deposition of loess and on the character of metamorphosed minerals supposed to be of eolian origin. For the solution of these problems it is necessary to measure the quantity of dust precipitated per unit area, especially in rain and snow, and to separate the sizes and kinds of material. The best plan is to measure off a square yard or a square meter and brush up the dust, if dry, or to shovel into a tub all of the dust-bearing layer of snow or sleet. Rain with contained dust is best collected from the ordinary Weather Bureau raingages of 8 inch, or 14 inch, diameter.

Determination of the soluble materials in a dustfall is especially important as thus may be learned the rate of deposition of potassium and other natural fertilizers to eastern soils by air transport from the arid

west. These soluble materials can only be saved by evaporation of the rain or snow.

Samples collected for weighing and sizing will also suffice for mineralogical and chemical analysis. The identification of diatom tests, spores, pollen, and cellular tissue can also be made from the same material. Detection of viable spores demands so much care to avoid contamination, that it is best to notify specialists in plant pathology of the dustfall, and invite them to collect material for incubation before the dustfall disappears.

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THE DUSTFALL OF NOVEMBER 13, 1933, AT BUFFALO, NEW YORK

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ABSTRACT

Atmospheric dust precipitated with rain at Buffalo, New York, on November 13, 1933, was found to contain materials characteristic of a semi-arid climate—e.g. dried-up playa lakes or flood-plain areas. Ninety per cent of the material is inorganic, the rest diatom tests, spores, pollen and shreds of leaves, bark, etc. The sizes of the particles range from 0.005 to 0.5 mm., averaging 0.02 mm.

On the morning of November 13, 1933, snow which had fallen several days previously, and which covered the ground to a depth of 5 inches, was observed to be discolored. In order to avoid contamination, only the top few inches of fresh snow were collected. This snow was melted, the liquid filtered, and the residue mounted in Canada balsam, then examined with polarized light under the microscope.

The assemblage of organic and inorganic matter which composes the Buffalo grit, and represents a mixture of materials derived from widely scattered areas in the west and northwest, is characteristic for the most part, of dried-up playa lakes and ponds, or of flood plain areas.

Diatom tests	Feldspar
Pollen	Hornblende
Spores	Mica
Vegetable fibers	Quartz
	Tourmaline
	Volcanic Glass
	Zircon

There are two kinds of volcanic glass in the dust. In transmitted light one variety is colorless and contains inclusions which may be either liquid or gaseous. The other variety is black and suggests basaltic glass. The feldspar is unaltered. It consists of orthoclase,

microcline, and plagioclase feldspar. These mineral grains are angular to subangular in appearance. The quartz and feldspar examined from the Buffalo dust fall are glassy clear and are not at all stained by iron oxide as were those in the Madison dustfall of 1918 concerning which Winchell and Miller (1) say "both the quartz and the feldspar are stained by limonite and hematite, and this condition seems to pervade the fragments so thoroughly that it is a condition of long standing." The mica is mainly muscovite, although a green variety present probably represents some form of biotite. Brown and blue-colored tourmaline is present as is colorless zircon. Both of these minerals are distinctly euhedral.

The hornblende is light-green and possesses the characteristic prismatic cleavage of the amphiboles. Most of the mineral grains present are subangular to angular, but a few minute undetermined colorless grains, showing abnormal berlin blue interference colors under crossed nicols suggestive of vesuvianite or zoisite, are distinctly rounded or subrounded.

Winchell and Miller (2), speaking of the Madison dustfall of 1918, state that "microscopic measurements of the size of the particles show that they range from about 0.003 mm. to 0.1 mm., but a surprisingly large percentage falls within much narrower limits, namely 0.008 to 0.025 mm." The range of the diameters or lengths of the Buffalo dust particles varies from 0.005 to 0.5 mm., while a large percentage of the dust averages 0.02 mm. A little of the dust was spread out on a black sheet of paper and it was seen that a few colorless grains were just large enough to be visible to the naked eye.

About 10 per cent of the entire sample consists of organic matter. According to Mrs. Imogene Robertson, assistant curator of biology of the Buffalo Museum of Science, the organic matter consists of spores of microfungi, ferns, mosses, and encysted protozoans. The spores seen present a variety of forms and shapes. Some are spherical, others ovoid, still others distinctly elongated. Some of the varishaped spores are smooth, some are pitted, and a few are distinctly spinous.

According to Winchell and Miller, the Madison 1918 dustfall consists mainly of feldspar, quartz and diatom tests, with some minor amounts of other constituents, and Twenhofel (3) suggests that the place of origin was the semiarid regions of New Mexico, Arizona, and adjacent states. The assemblage of organic and inorganic matter which composes the Buffalo grit, however, is characteristic for the most part, of dried-up playa lakes and ponds, or of flood plain areas.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 2, PP. 83–88, FIG. 1,
AUGUST, 1934

HEAVY MINERALS OF THE ORDOVICIAN SEDIMENTS OF ONTARIO

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ABSTRACT

The following observations are the result of an attempt to separate and study such heavy minerals as occur in the sediments, mainly impure limestones and shales, of Upper and upper Middle Ordovician age, in Ontario. The specimens studied are from three localities: Lake Ontario, Georgian Bay, and Manitoulin Island. As was expected, many of the sediments contain very few heavy detrital minerals, but some, notably the Meaford and Dundas formations, gave good results. The characteristics of the heavy minerals are described. In the Dundas a difference is noted between the heavy minerals near Lake Ontario and those at Manitoulin Island, the latter showing characteristics of a nearby pre-Cambrian source. Marked similarity in the heavy minerals of the Meaford and the Dundas of the Lake Ontario district is noted. The presence of authigenic feldspar in the Dundas hard bands is recorded.

The Paleozoic sediments of Ontario have not, so far as the writer is aware, been studied from the standpoint of heavy mineral content. Heavy mineral residue have been made use of in other districts, especially in Europe, not only for separating beds or correlating them, but also for establishing facts about the conditions of deposition, such as distance from shore, or direction of drainage or currents. It seemed worth while, therefore, to try some preliminary work in this connection on the rather unpromising material of the Upper and upper Middle Ordovician sediments of western Ontario between Lake Ontario and Manitoulin Island. The rocks are mainly limestones and shales and tend to yield very meager crops of heavy minerals.

In order to get some idea of how beds of the same horizon varied in different localities, specimens were selected from three regions, Manitoulin Island, the south end of Georgian Bay of Lake Huron, and along the north shore of Lake Ontario.

PROCEDURE

Since most of the rocks are calcareous to some degree, acid digest in hydrochloric acid was the first treatment. The harder rocks were ground to pass 48 or 65 mesh before acid digest. Water was poured onto the ground rock first and the acid added, a little at a time, until the concentration was about 50 per cent. When no more action resulted on adding fresh acid and water the dissolved material and suspended sludge were poured off and the residue washed well in water. The residue was then dried, powdered gently if this was necessary, and placed in a separating funnel in Thoulet solution (Potassium-Mercuric Iodide) slightly diluted with water to give a specific gravity of 2.9. The heavy min-

erals which sank were collected on a filter paper, washed, dried, and mounted on slides in Canada balsam for microscopic examination.

STRATIGRAPHIC SUCCESSION

The succession from which specimens were obtained in the three localities is as follows:

	Lake Ontario
Richmond	Queenston Meaford
Dundas	Credit Humber Danforth Rosedale
Gloucester	Blue Mt.
Collingwood	Collingwood
Cobourg	Cobourg
Trenton	Upper Trenton

MICROSCOPIC EXAMINATION OF HEAVY MINERALS

As will be seen below, many of the purer limestones and shales contain no recognizable heavy detrital minerals. In cases where only one or two such grains appeared on the slide, especially if they were larger or more angular than would be expected, no record is made, as the possibility of the sample being contaminated with one or two grains of other material in the laboratory is hard to avoid. When there are few or no detrital minerals, authigenic minerals such as pyrite, marcasite or anhydrite may be of same value in correlation but too much faith should not be placed in minerals of this type which are apt to vary greatly from place to place. In general, the more detrital grains of recognizable size there are, the fewer authigenic minerals, and vice versa.

The characteristic features of the heavy mineral residues of the different beds are as follows:

Richmond.—(a) Queenston. The red Queenston shale is a very unsuitable rock for providing criteria of this nature. The commonest mineral in the heavy residue in samples from Lake Ontario and Georgian Bay is granular hematite, and pyrite is fairly common at the latter locality. Of detrital grains, a single tourmaline from a specimen from Georgian Bay, and a few garnet and hornblende grains, are of doubtful authenticity.

From Manitoulin Island a specimen yields little or no hematite and only a little authigenic pyrite. The detrital minerals are not abundant, but include leucoxene, magnetite or ilmenite, epidote, hornblende and a few grains of doubtful identity.

(b) Meaford. The more arenaceous nature of the rocks of the Meaford afford much more opportunity for heavy mineral separation. From the Lake Ontario locality a specimen yielding a good separation has not yet been obtained, but with further work material with a fair proportion of heavy minerals should be obtainable.

A specimen from the Vincent member of the Meaford of Workman's Creek, Georgian Bay, gave an excellent suite of heavy minerals. Of authigenic minerals pyrite and marcasite are usually absent, but some rather large grains of deep-blue anatase are probably of authigenic origin, resulting from the decomposition of leucoxene grains. Of detrital grains, leucoxene is most abundant, approximating 47 per cent of the total heavy mineral con-

tent. The leucoxene was probably originally ilmenite, but the latter may have been altered to, or at least coated with, leucoxene before being deposited. Zircon is the next most common mineral (about 28 per cent of the total heavy minerals), occurring in rather well-rounded, clear grains, the majority not showing zoning. Some long, prismatic grains are found with terminations rounded or broken off. Tourmaline comes third in abundance (8 per cent), brown, green, blue and almost colorless grains being found.

Georgian Bay	*Manitoulin Is.*
Queenston	Kagawan
Meaford	Meaford
Christie	
Humber	Wewemikongsing
Danforth	
Rosedale	Sheguiandah
Blue Mt.	
Collingwood	Collingwood
Cobourg	
Upper Trenton	*Upper Trenton*

Magnetite forms about 6 per cent and colorless or pale garnet 4 per cent. Rutile is present but is not as common as might be expected. Other occurrences are hornblende, chlorite, topaz, ilmenite, staurolite, biotite, hypersthene, augite, and possibly titanite. All the grains except the authigenic anatase, are of small, even size and are fairly well-rounded (fig. 1*a*).

Specimens from Manitoulin Island did not yield any heavy mineral crop comparable with that from Georgian Bay. Pyrite and marcasite of authigenic origin are commonest. There is a black, opaque mineral in large grains which might be ilmenite, but is more likely to be an authigenic mineral such as melnikowite (FS_2). A yellowish to deep-brown, isotropic mineral may be sphalerite, but the limited amount of material available has not made positive identification possible.

Dundas.—The Dundas at Toronto consists of shale, with bands of impure limestone and calcareous sandstone. The last-mentioned type gives good heavy mineral separations, the shale meager ones, and the limestone little or nothing. Specimens from calcareous sandstone bands of the Humber member give particularly good results. Practically all the heavy minerals are detrital, marcasite and pyrite being rare. Leucoxene forms between 20 and 50 per cent of the heavy minerals, occurring in small nodular grains. Zircon is next most abundant (up to 40 per cent), with most grains clear, colorless and well-rounded. Brownish grains of zircon, however, showing zoning, are considerably more common than in the Meaford mentioned above. Tourmaline forms about 8 per cent, mainly in characteristically rounded, olive-brown grains, though blue and green grains are also found. Garnet in rather irregular colorless grains comprises about 8 per cent, and apatite, in round grains, is fairly common in some bands. Other occurrences include hornblende, augite, diopside, topaz, magnetite, chlorite, hypersthene, epidote, and biotite (fig. 1 *b, c*).

It is interesting to note that in the light crop of minerals from these "hard bands" feldspar is an abundant constituent. Both microcline and albite have been positively identified and orthoclase may occur as well. Since

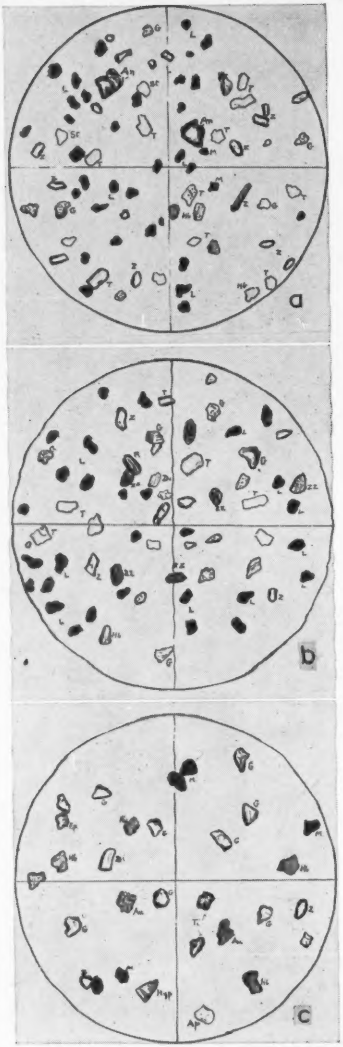

FIG. 1. Heavy minerals of the Meaford and Dundas hard bands. (a) Meaford of Georgian Bay, Ontario, X30. (b) Dundas hard bands at Toronto, X30. (c) Dundas hard bands at Manitoulin Island.

An—Anatase, Ap—Apatite, Au—Augite, Di—Diopside, Ep—Epidote, G—Garnet, Hb—Hornblende, Hyp—Hypersthene, L—Leucoxene, M—Magnetite or ilmenite, R—Rutile, St—Staurolite, T—Tourmaline, Ti—Titanite, Z—Zircon (clear), ZZ—Zoned zircon.

most of these grains are angular and irregular, and since minerals as unstable as the feldspars would not be expected to occur abundantly in a relatively deep water deposit, it seems probably that most, if not all, this feldspar is authigenic, having grown in place, deriving its chemical constituents from the argillaceous material present. Albite especially has been described recently from various localities, occurring as an authigenic mineral in calcareous muds, shales, etc.

No specimens suitable for heavy mineral separation have been obtained from the Dundas of Georgian Bay as yet.

From Manitoulin Island specimens have been obtained yielding a fairly extensive suite of detrital minerals. These differ markedly from those of Toronto specimens. Garnet, in pink to colorless, rather angular grains, is the most common heavy mineral (up to 40 per cent). Magnetite (probably some ilmenite is included) forms about 19 per cent of the total and dark-green hornblende, in stumpy rounded prisms about 14 per cent. Zircon and leucoxene, so common in the Toronto specimens, are both comparatively rare, each forming not more than 4 per cent of the total heavy minerals. Epidote is not uncommon, and the same can be said of augite, hypersthene, titanite, and apatite. Topaz and tourmaline are rare. The whole assemblage suggests a derivation directly from pre-Cambrian rocks at no great distance and deposi-

tion in shallow waters or in strong currents. The relatively large size of the grains and lack of rounding support this suggestion.

Another specimen from a more calcareous band on Manitoulin Island, yielded very few detrital minerals but much more authigenic pyrite and marcasite. A specimen from the Sheguiandah formation on Manitoulin Island, corresponding either to the Lower Dundas or to the Blue Mountain of the Lake Ontario region, yielded granular marcasite but no detrital minerals except one or two small zircons.

Gloucester.—In a specimen from from the Blue Mountain formation from the Rouge river, near Lake Ontario, the heavy mineral residue obtained was small and consisted mainly of hematite and a black, opaque mineral (melnikowite?) often coated with hematite. Both these minerals look too coarse and irregular to be of detrital origin.

From the Georgian Bay region a specimen of shaly limestone from the Blue Mountain formation was treated. This contained abundant finely crystalline marcasite in nodules, which must be authigenic. A yellowish white, opaque mineral may be leucoxene, though the fragments look larger than would be expected from altered ilmenite grains. Detrital grains of hornblende, garnet, augite, and rutile occur, but are very rare, and, therefore, not of much value in correlation.

Collingwood.—The Collingwood black shale is very unpromising for the recovery of recognizable detrital grains. The only specimen treated was collected on Manitoulin Island. As expected, the only heavy minerals obtained were authigenic, consisting of pyrite cubes, some with later encrustations of fine pyrite or marcasite on their sides. Two grains of blue anatase, also presumably authigenic, were observed.

Cobourg.—The Cobourg formation was also evidently laid down in waters too deep or too calm to allow deposition of detrital minerals of recognizable size. One specimen from Georgian Bay was treated. It yielded dark finely granular marcasite and a few large crystals of pyrite, together with some hematite, derived from oxidation of marcasite. No detrital minerals were recognized.

Trenton.—Little work has as yet been done on Trenton specimens. Although at first sight not a promising rock for this type of examination, some specimens from Manitoulin Island, where the Trenton limestone overlaps and lies directly on the pre-Cambrian rocks, yielded some heavy detrital minerals. In one specimen the authigenic minerals consisted of pyrite, marcasite, anhydrite, and a grain of anatase. Of detrital heavy minerals hornblende is commonest (about 40 per cent of total heavy minerals), followed by garnet (15 per cent) and zircon (10 per cent). Other occurrences include topaz, epidote, biotite, tourmaline, diopside, and augite. The total crop is small. As expected, the minerals are such as would be derived from the erosion of a pre-Cambrian land mass.

CONCLUSIONS

From the above results it may be seen that in several horizons of the

Upper Ordovician of Ontario interesting assemblages of heavy minerals may be recovered. The more sandy bands of the Meaford and of the Dundas give especially good results, while the Upper Trenton is promising.

Features which stand out are:

(1) The general similarity of the heavy mineral assemblage of the Georgian Bay Meaford and the Toronto Dundas hard band. In both, leucoxene is most abundant, then zircon, tourmaline and garnet. The Dundas is differentiated by having many zoned, dark zircons and brown tourmaline.

(2) The difference between the heavy minerals of the Dundas in Toronto and in Manitoulin Island. The latter, lacking leucoxene, with few zircons, and an abundance of garnet and hornblende, is characteristic of a shallow water deposit near a pre-Cambrian shore.

(3) An assemblage rich in garnet and hornblende from the Manitoulin Trenton again is characteristic of a shallow water, near-shore deposit.

(4) In these beds correlation by means of heavy minerals over distances such as those between the three localities chosen does not seem feasible.

This is only preliminary work and it would be unwise to draw many conclusions from the scanty evidence so far obtained. It is hoped that after further investigation in these beds, and work along similar lines in other districts, there may be forthcoming information of real value to the interpretation of Paleozoic stratigraphy. At present Mr. A. Holstein is working on these lines on the Silurian succession of Western Ontario.

The writer is indebted to Dr. M. Fritz and to Mr. J. Caley for specimens and much helpful information.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 4, NO. 2, PP. 89-95, TABLES 1-2, FIG. 1, PL. 1,
AUGUST, 1934

AUTHIGENIC FELDSPAR IN SANDSTONES OF SOUTHEASTERN MINNESOTA

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ABSTRACT

Feldspar grains of sandstones of southeastern Minnesota are characterized by secondary enlargements. Detailed study of the feldspar of the New Richmond sandstone shows rounded detrital grains of microcline have been enlarged by growth of orthoclase. The feldspar enlargements may possibly represent a sedimentary product, but an alternate hypothesis of hydrothermal origin is also considered.

Feldspar grains of sandstone of southeastern Minnesota are rarely well-rounded and commonly occur as euhedral crystals. Graham[1] noted the presence of these crystals in the Cambrian sandstones of the state. A study of the New Richmond sandstone of Ordovician age revealed the interesting fact that the angularity of the feldspar is due to secondary enlargement of rounded detrital grains of this mineral. Similarly, samples of the Jordan, St. Lawrence, Franconia, and Dresbach sandstones all show secondary enlargement of more or less rounded feldspar grains. The same feature has been observed in the St. Peter sandstone by Thiel and Berg who also found crystals of feldspar formed by enlargement of detrital grains in the Oneota dolomite and Platteville limestone.[2] A wide areal distribution is indicated by the presence of enlarged feldspar grains in samples of sandstones from southeastern Minnesota together with a few samples from Wisconsin.

This paper will be devoted chiefly to a consideration of the New Richmond sandstone. Samples of this sandstone were collected by Dr. C. R. Stauffer of the University of Minnesota during the summer of 1931. Drs. G. A. Thiel, G. M. Schwartz, and C. E. Dutton generously supplied additional samples of the New Richmond and of the Cambrian sandstones. The writer is indebted to Dr. C. K. Wentworth of Washington University and to Dr. Thiel of the University of Minnesota for assistance in the preparation of this manuscript and for helpful suggestions during the course of the investigation.

THE NEW RICHMOND SANDSTONE

The New Richmond sandstone is a fine-grained, well-sorted, generally friable sandstone composed chiefly of quartz grains with a small percentage of feldspar and carbonate and a small

[1] Graham, W. A. P., A textural and petrographic study of the Cambrian sandstones of Minnesota: *Jour. Geology,* vol. 38, p. 706, (see fig. 4 E), 1930.

[2] Thiel, G. A., and Berg, G., Written communication, Nov. 8, 1933.

fraction of heavy minerals. On the average, grains one-eighth to one-fourth mm. in diameter constitute 65 per cent of the sandstone. Secondary enlargement of the quartz grains is prominent in some samples and almost lacking in others. The heavy minerals include anatase, biotite, corundum, garnet, ilmenite, leucoxene, muscovite, tourmaline, an amphibole, and dioptase (?). The color of the sandstone varies from white to yellowish-brown depending upon the amount of limonite which locally cements and discolors it.

FELDSPAR IN THE NEW RICHMOND SANDSTONE

Feldspar is rarely observed among the larger grains of the sandstone. From the data of Table 1, it is estimated that feldspar grains compose between 1 and 2 per cent of a sample of the New Richmond sandstone from Lake City, Minnesota. The percentages of Table 1 were obtained by separating the feldspar from the other minerals of the sandstone by means of bromoform diluted with alcohol, the feldspar being recovered as the float fraction. By making repeated separations a final product was obtained consisting of feldspar grains, the specific gravity of which as determined with a pycnometer at 25° C. was 2.541. The chemical analysis of this material is given in Table 2.

TABLE 1. *Distribution of feldspar by sieve size in a sample of the New Richmond sandstone from Lake City, Minnesota.*

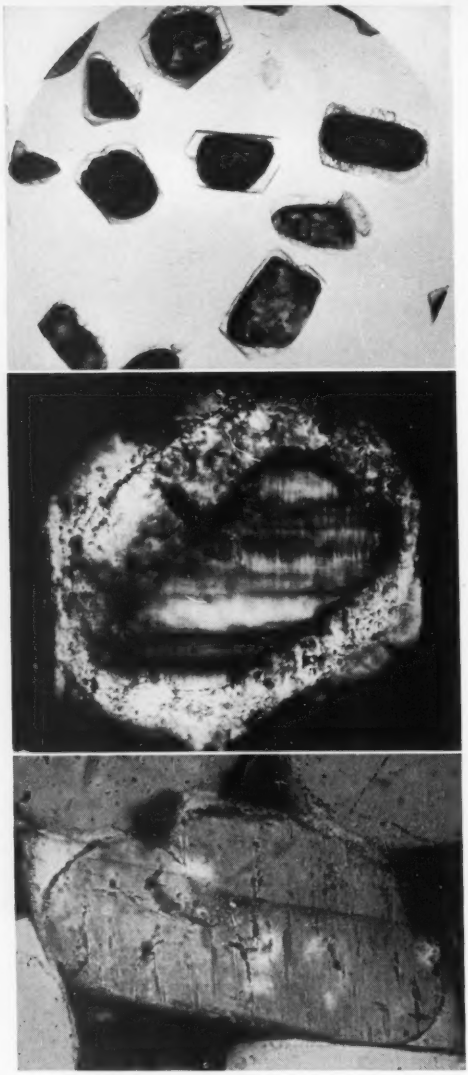
Sieve openings in millimeters	*Per cent of sample by weight*	*Feldspar in each grade, per cent of fraction*
.701	.03	none
.495	1.11	none
.351	4.78	none
.246	24.18	none
.175	43.36	not determined
.124	21.50	3
.088	2.36	9
.061	1.00	11
−.061	1.68	not determined

TABLE 2. *Composition of New Richmond sandstone feldspar showing secondary enlargement. S. Goldich, analyst.*

SiO_2	64.94		
Al_2O_3	18.51		
Fe_2O_3	0.15	K-feldspar	92.0
MgO	0.06	Na-feldspar	5.6
CaO	0.18	Ca-feldspar	0.9
Na_2O	0.66	Kaolinite	0.4
K_2O	15.55	Hematite	0.15
H_2O—	0.05	Quartz	1.0
Ign. loss	0.16		
TiO_2	Trace		100.05
	100.26		

As seen in transmitted light the feldspar grains consist typically of a rounded nucleus and an outer angular zone. In its growth this marginal material has tended to develop crystal faces and to assume crystal forms which result in the euhedral shapes and in the angularity of the feldspar. Physical and optical properties of the nucleus and the rim clearly define and set off the original feldspar from the secondary growth. Usually the nuclei are sufficiently altered so that the rounded detrital feldspar is in marked contrast with the clear, unaltered secondary material. A film of iron oxide or a fringe of what appears to be organic matter often marks the contact of the two zones.

The nuclei of the great majority of the grains seem to be the triclinic potash feldspar, microcline. The marginal growths, however, appear to be more nearly the monoclinic variety, ortho-



A

B

C

PLATE 1.

Photomicrographs showing enlarged feldspar grains from the New Richmond sandstone, Minnesota.

A—Secondary enlargement of detrital feldspar grains. 1/16-1/8 mm.

B—Feldspar grain from Mankato. The innermost zone is microcline. Two zones of secondary orthoclase are present. The rounded outline of the first conforms roughly to the shape of the original microcline grain. Crossed nicols. Width of grain—.09 mm.

C—A thin section of the New Richmond sandstone from Lake City showing enlargement of a feldspar grain developed around an interfering quartz grain. Crossed nicols. Length of grain—.12 mm.

clase, so that the zones are clearly defined in basal sections between crossed nicols. Extinction of original and secondary portions of the grains in (010) sections is simultaneous. Measurements on the nuclei of a great number of grains consistently gave an extinction angle on (001), X to (010), of 15° and of 5° on (010). In some of the grains the basal section with a typical extinction angle of 15° appears to be untwinned; in other grains albite twinning is prominent; whereas, in still others, combined twinning after both albite and pericline laws results in the "grating-structure" characteristic of microcline. Twinning lamellae of the central portion end abruptly at the contact with the secondary feldspar into which they never extend. Indices of refraction of the secondary feldspar for sodium light are *alpha*, 1.518; *beta*, 1.523; *gamma*, 1.525. Indices of refraction of the microcline are very near the above values but seem to be slightly higher. Optical relationships of the secondary to the original feldspar are shown in the diagrams of Figure 1.

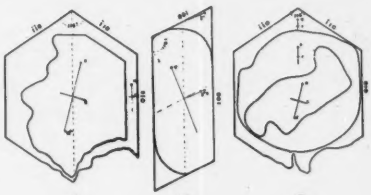


FIG. 1. Diagrams showing optical relationships in enlarged feldspar grains. A. (001) section; B. (010) section; C. (001) section of a grain showing two zones of secondary orthoclase.

EVIDENCE THAT THE SECONDARY FELDSPAR IS AUTHIGENIC

The rounded shapes of the original feldspar grains indicate a comparatively long sedimentary history before their deposition. This is further shown in the elimination of the sodic- and calcic-feldspar which might be expected in a sandstone derived from an igneous or metamorphic terrane as well as by the rounding of the heavy minerals such as tourmaline and zircon. The sharp crystal boundaries of the enlarged feldspar suggest that the growths are authigenic. The relationships of these secondary growths to the adjacent quartz grains as is seen in thin section likewise show that the enlargements were developed *in situ* (Plate 1, *c*).

A noteworthy development of secondary feldspar is found in the New Richmond sandstone from Mankato, Minnesota. The grains of this sandstone probably have gone through a number of sedimentary cycles, but evidence for at least two is preserved. Some of the quartz grains originally rounded were enlarged by the addition of silica and then rounded again to their present shapes. Many of the feldspar grains have gone through the same cycle except that they show three zones indicating the rounded grains were enlarged, rounded, and then again enlarged. Two periods of growth separated by an interval of abrasion are thus shown (Plate 1, *b*).

ORIGIN OF THE FELDSPAR

The term authigenic, according to Holmes,[3] was first used by Kalkovsky

[3] Holmes, Arthur, The nomenclature of petrology (second edition), pp. 39-40, 1928.

in 1880 and means *"generated on the spot,"* but not necessarily contemporaneous with the sediment or rock—authigenic minerals may be later. Because the authigenic character of feldspar can be proved, it does not follow that the feldspar is a sedimentary product, though the term has been used in this sense. Two hypotheses to explain the origin of the feldspar enlargements seem to be worthy of consideration: 1, a sedimentary origin, and 2, an igneous (hydrothermal) origin.

Sedimentary Origin.—The origin of authigenic feldspar in calcareous rocks has long been a subject for speculation among European geologists, but there has been a growing tendency to accept a sedimentary origin for this mineral. In view of this tendency, it is logical to consider such an origin for the authigenic feldspar described in this paper.

A comprehensive review of the literature on authigenic feldspar would unnecessarily lengthen this paper, especially in view of the summary recently published by Boswell.[4] A classic occurrence and the one most frequently cited as proof of the sedimentary origin of feldspar is that of the Paris Basin. This feldspar was first studied by Cayeux,[5] and later by Grandjean[6] who identified it as microcline. Grandjean suggested that the feldspar grew in the calcareous ooze at the time of deposition, and that with the burial of the ooze, the feldspar ceased to grow. He further suggested that feldspar may be growing on the sea-floor at the present time. De Lapparent[7] thought certain algae may be instrumental in the formation of authigenic feldspar.

Another view as to the time and manner of formation is given by Miss Reynolds[8] who thinks feldspar may be formed through the action of ground water, while Mügge[9] has described what he regards as further growth of orthoclase in soil. If Mügge's observations are accepted, they indicate that a "new growth of feldspar was observed under conditions which at least exclude the presence of high temperatures."

Miss Reynolds' study of the Triassic sandstone of northeastern Ireland seems to be the only one in which a sedimentary origin is proposed by the investigator for feldspar in a sandstone. She also found authigenic feldspar in the Magnesian Limestone from Roker (Sunderland), England. The feldspar of this formation closely resembles that of the Minnesota sandstones in that the crystals are zoned. The central portions are microcline, and the outer, orthoclase. The boundary between the zones is said to be "irregular but approaches oval," but the possibility of the crystals being en-

[4] Boswell, P. G. H., On the mineralogy of sedimentary rocks, pp. 87-96, 1933.

[5] Cayeux, L., Existence de nombreux cristaux de feldspath orthose dans la craie du bassin de Paris. Preuves de leur genèse in situ: *Compt. Rend. Acad. Sci. Paris,* vol. 120, pp. 1068-1071, 1895.

[6] Grandjean, F., Propriétés optiques et genèse du feldspath néogène des sédiments du bassin de Paris: *Compt. Rend. Acad. Sci. Paris,* vol. 148, pp. 723-725, 1909.

[7] De Lapparent, J., Sur les cristaux de feldspaths développés dans les calcaires du Crétacé supérieur pyrénéen: *Compt. Rend. Acad. Sci. Paris,* vol. 167, pp. 784-786, 1918.

[8] Reynolds, Doris L., Some new occurrences of authigenic potash feldspar: *Geol. Mag.,* vol. 66, pp. 390-399, 1929.

[9] Mügge, O., Weiterwachsen von Orthoklas im Ackerboden: *Centr. Min.,* p. 123, 1917.

larged detrital grains is not considered. Optical relationships of central and outer zones are the same as described for the New Richmond sandstone feldspar.

Contribution of North American writers to the problem of authigenic feldspar seems to be limited to two papers, the first by Daly[10] appearing in 1917. Daly found feldspar in the Waterton dolomite just north of the boundary between Montana and Alberta at Waterton Lake. Singewald and Milton[11] have described authigenic feldspar from the Trenton limestone at Glens Falls, New York. In both of these occurrences the sediment is considered to be a chemical precipitate. Daly excludes metamorphism in the formation of the Waterton feldspar and suggests that this mineral may crystallize in calcareous muds at temperatures below 100° C. and probably below 70° C. Singewald and Milton advocate a sedimentary origin for the feldspar of the Trenton limestone which they believe contained much organic matter. Heat attending chemical decomposition may have caused temperatures slightly higher than normal at the time of formation of the feldspar.

The association of authigenic feldspars with marine calcareous rocks and the common presence of organic matter in the crystals have led to the suggestion that lime, salt water, and organic matter are probably involved in their formation. In the secondary feldspar of the New Richmond sandstone inclusions of what appears to be organic matter are common. Small amounts of calcite are present, and the sandstone is undoubtedly marine. However, the presence of the organic matter in the feldspar may be entirely incidental. The inclusions may be the result of the solution of organic matter in alkaline waters and its deposition and incorporation at the time of growth of the feldspar. Clarke[12] in an analogous case, that of the reputed ability of organic matter to hold silica in solution, suggested that the relation between humus and silica is purely coincidental, the presence of both being the result of a common solvent.

The presence of organic matter indicates reducing conditions, and while such conditions do exist below the water table, ground water circulation under present day conditions does not seem to be an adequate agency for the formation of the feldspar enlargements. The amount of secondary quartz growth might be an indication of the activity of the ground water, but as has been pointed out, the enlargements of the feldspar grains seems to be independent of the quartz enlargement.

A more plausible explanation is in line with the prevailing idea that the formation of authigenic feldspar probably takes place at the time of deposition of the sediment or during the period of consolidation. It has been suggested that increased temperatures

[10] Daly, R. A., Low-temperature formation of alkaline feldspars in limestones. *Nat. Acad. Sci., Proc.*, vol. 3, pp. 659-665. 1917.

[11] Singewald, J. T., Jr., and Milton, Charles, Authigenic feldspar in limestone at Glens Falls, New York: *Geol. Soc. America, Bull.*, vol. 40, pp. 463-469, 1929.

[12] Clarke, F. W., Data of geochemistry: *U. S. Geol. Survey, Bull.* 770, p. 111, 1924.

due to deep burial of sediments may have been important in the genesis of feldspar, but there is little probability that the sandstones under consideration have been buried to depths sufficient to raise their temperature appreciably.

Igneous (Hydrothermal) Origin.—The cold water origin of silicates such as potash feldspar is not universally accepted by geologists, largely because of the failure of all attempts to produce these minerals in the laboratory under normal conditions of pressure and temperature. Kroustchoff[13] synthesized potash feldspar by hydrochemical means at 300° C. A low-temperature form of orthoclase, valencianite, however, is known to occur in veins the temperature of formation of which is believed to be about 100° C. or less. The occurrence of this mineral in metalliferous deposits has been discussed by Lindgren.[14]

Hydrothermal solutions of magmatic origin of temperatures of about 100° C. rising under pressure might conceivably penetrate sedimentary rocks without leaving notable signs of hydrothermal activity. Such solutions may be responsible for the presence of authigenic feldspar suggested to be sedimentary because they occur in rocks lacking indications of igneous action. Emmons[15] believes the ore deposits of the Mississippi valley are of hydrothermal origin. If the thermal waters of magmatic origin are responsible for the sulphide deposits of southwestern Wisconsin, northwestern Illinois, and northeastern Iowa, it seems possible that the enlargements of the feldspar grains in the sediments just north of this region may be the result of hydrothermal solutions related to the ore-bearing solutions. Emmons thinks the sulphide ores were probably formed at the time of the Appalachian revolution, but the feldspar grains of the New Richmond sandstone at Mankato were apparently partly enlarged in pre-New Richmond time.

Newhouse[16] by studying liquid inclusions containing bubbles in sphalerite from the ore deposits of the Mississippi valley was able to determine what he believes to be the temperature of formation of the sphalerite. Sphalerite from Wisconsin is said to have formed between 80° and 105° C. This is the range within which adularia, or valencianite, might be expected to form.

It is difficult to understand why, if microcline can be formed by sedimentary processes, this mineral rather than orthoclase did not develop on the triclinic nuclei. While microcline has never been reported in low-temperature veins, valencianite is rather common, and the apparent discrepancy is more easily explained, therefore, by a hydrothermal origin hypothesis. Newhouse also determined the temperature of formation of sphalerite from the southeastern Missouri lead district and found it to be 105°-125° C. It is an

[13] Kroustchoff, K., *Compt. Rend. Acad. Sci. Paris*, vol. 104, p. 603, 1887.

[14] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar and other mining districts in Idaho: *U. S. Geol. Survey, 20th Ann. Rep.*, Pt. 3, pp. 166-168, 1900.

[15] Kroustchoff, K., *Compt. Rend. Acad.* posits of sulphide ores of the Mississippi valley: *Econ. Geology*, vol. 24, pp. 221-271, 1929.

[16] Newhouse, W. H., The temperature of formation of the Mississippi valley lead-zinc deposits: *Econ. Geology*, vol. 28, pp. 744-750, 1933.

interesting coincidence that authigenic feldspar also occurs in the Bonneterre dolomite, the ore-bearing formation in this district. In an insoluble residue obtained from a drill core passing through the Bonneterre dolomite in St. Francois county, H. S. McQueen found what appeared to be well-developed rhombohedrons of a mineral identified by the writer as feldspar, the crystals being rather typical of the habit of adularia. According to McQueen the sample yielding the feldspar was taken about 20 feet below the top of the formation.

The drill core shows the Bonneterre to be a finely-crystalline dolomite dark-gray in color. The feldspar occurs as a druse lining the vugs and cavities of the dolomite. The crystals average about .15 mm. in greatest dimension and might easily be confused with rhombohedrons of calcite or dolomite except for their insolubility in acids. The Bonneterre feldspar is without doubt later than the lithification of the dolomite, and it seems likely that it is hydrothermal and probably related to the mineralization of the district. This possibility suggests a similar relationship between the authigenic feldspar of the Minnesota and Wisconsin sediments and the ore deposits of the Upper Mississippi valley.

SUMMARY AND CONCLUSIONS

Authigenic feldspar occurs in the sediments of southeastern Minnesota chiefly as enlargements of detrital grains. Detailed study of the feldspar of the New Richmond sandstone shows that detrital grains of potash feldspar, largely microcline, have been enlarged by growth of orthoclase. The possibility of the authigenic feldspar being of sedimentary origin is considered and finds support in the similarity of the occurrence to that of other feldspars for which such an origin has been suggested. An alternate hypothesis is that the enlargements are hydrothermal. Arguments for this origin rest upon the association of the authigenic feldspar with the Mississippi valley ore deposits. Contributory evidence is found in the investigations of Emmons and Newhouse and in the presence of authigenic feldspar in the Bonneterre dolomite of the southeastern Missouri lead district.

A detailed study of the feldspar of the other formations and of its areal distribution may result in the discovery of facts which will enable a more positive statement of the origin. Examination of the literature indicates some confusion both as to usage of terminology and as to facts related to specific occurrences of sedimentary feldspar.

FRY, W. H. *Petrographic Methods for Soil Laboratories,* U. S. Dept. of Agric., Tech. Bull. 344, 96 pp., Jan. 1933, Supt. of Documents, Washington, D.C. 10 cents.

This bulletin is in reality an abbreviated textbook on the identification of mineral grains. The first 62 pages is devoted to the concise discussion of the properties of light and the fundamentals of optical methods used in the identification of mineral grains. The author was trained as a geologist and has therefore not overlooked the viewpoint of those interested in mineral grains as sedimentary deposits.

Considerable space is devoted to the important item of calibration of instruments used and to the methods of measurement used for grains. Especially noteworthy is the description of the methods for measuring thicknesses and areas. There is little that is new but the approach possesses the type of clarity most appreciated by the worker of limited experience. Cautions as to limitations of methods are inserted where needed and will prevent, if followed, needless waste of time, and will make for accuracy.

The oils recommended for immersion media are those suggested by Larsen, which still leave something to be desired in the range of the higher indices. The method used for determining the 3 indices of refraction of immersed grains is clear and usable. This should be welcomed by all students of grains.

The last 36 pages is devoted to the "Application of Methods." Under this heading the following are discussed: pure substances, minerals in soils, mechanical analysis, differentiation of soil colloids from crystalline material, organic matter, shape of particles, residues from the evaporation of soil solutions, soil structure, fertilizer materials, phase-rule problems, etc. An identification table similar to that of Larsen and a bibliography of 20 titles conclude the bulletin.

Publications of this character frequently escape the notice of geologists and most of them in fact do not approach the subject from the geologist's point of view. This one does. It is distressing to learn that this is the last work of Mr. Fry. He had just finished work on the galley proof of this bulletin on the morning of his death, Dec. 27, 1932. He has served with the Bureau of Soils since 1911. Trained as a geologist at the University of North Carolina he realized the value of mineralogical methods in soil determination. As a review guidebook for students or a laboratory handbook for workers this bulletin can be recommended.

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YOUNG, ROBERT B., *Conditions of Deposition of the Dolomite Series,* Geol. Soc. South Africa, Trans., vol. 36, 1933, pp. 121-135.

Detailed study has been made of two sections of the Dolomite Series of the Transvaal (pre-Devonian), one section near the village of Boetsap in Griqualand West and the other about 200 miles east on the western Witwatersrand. The section near Boetsap is exposed along the Hol River, and that on the western Witwatersrand was obtained from two diamond drill cores. The author finds that the rocks in the two sections are divisible into three groups of varying depth "phases" as follows:

A shallow "phase" is characterized in part by laminated dolomite, of which some is in thick beds, by cross lamination, irregular alternations of calcareous muds and sands, "mud-cake" conglomerate and mud fragments, ripple marks, oolites and oncolites, beds of shale, and smaller forms of stromatolites.

A transitional "phase" is characterized by coarsely stromatolitic rocks, bands of shale, and generally massive bedding of laminated dolomites.

A deeper water "phase" is made up of

laminated, commonly flaggy dolomites, in which there is irregular stromatolitic doming.

The three phases are each two or more times repeated in each section.

(Mud-cake conglomerates are made up of flakes of mud both after the manner of edgewise conglomerates, on edge, and also with the flakes in more or less horizontal positions.

Stromatolites are bodies that are as a rule devoid of organic structure, but exhibit such similarities with calcareous algal growths forming in shallow lakes at the present day that they are believed to be of similar origin.

"Oncolite" is here used to designate those small oolite-like structures that have resulted from stromatolitic growth about detached nuclei; they are usually less than 3 mm. in diameter.)

The presence of free carbon and of stromatolitic growths in each of the three phases is ascribed to the activities of algae; the author thus concludes that the dolomites were deposited in waters that were never so deep as to prohibit the passage of light. From this it is adduced that the Dolomite Series was deposited in a shallow inland sea.

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SUJKOWSKI, ZB. *Radiolarites of the Eastern Polish Carpathians and their Comparison with those of Tatra.* Extract from the Bulletin of the Geological Survey of Poland, Vol. VII, part 1, 1933. Pp. 99-168.

SUJKOWSKI, ZB. *Radiolarites of the Lower Carboniferous of the St. Croix Massif.* Ibid. Vol. VII, part 4, 1932. Pp. 637-711.

These papers are printed in Polish. Each has a résumé in French representing an 85 per cent reduction from the Polish text. This affords at least partial access to the ideas and records of the author.

While focused by title upon the radiolarites of two Polish localities, these studies by Sujkowski really survey the more general field and at least in the matter of genesis they embrace the principal deposits of Europe. The deposits of the Carpathians and of the St. Croix Massif are in no sense neglected in essentials. The number of footnotes and quotations, many from English sources, indicate that the author has covered his field exhaustively. Furthermore, he has visited or had access to material from the principal deposit of Europe.

Sujkowski considers the radiolarites to be the fossil equivalents of modern radiolarian oozes or muds. The latter he has studied through the medium of material collected by the Challenger and other expeditions. Incidentally, he considers beds with 50-60 per cent of volume made up of the siliceous tests of radiolaria as true radiolarites. The series in which they occur may contain any proportion of the fossil remains.

Classification as fossil radiolarian oozes predicates deposition of the radiolarites in the deeper seas. Sujkowski supports this with lines of evidence which appear satisfactory to the reviewer. In the first place, he cites that the fossil material is dominantly pelagic with radiolaria taking the lead. Benthonic forms take a subordinate place. The radiolarian tests are very fine and delicate, they have even finer spines, yet they are rarely broken. There is no detrital material coarser than about 0.01 mm. Some lime carbonate shells occur but these are invariably corroded. The deposits cover considerable area.

Apparently deposition took place where access could be gained only from above, not laterally. From above, only surface-living forms were available. Life on the bottom was scanty. An occasional fish tooth is mentioned in the late Cretaceous deposits of the Carpathians. The fact that the radiolarian tests are intact, although fragile, indicates that there was a minimum of agitation correlating with the deeper sea. Carbonaceous and pyritic material present voluminously in some of

the deposits indicate the exclusion of oxygen.

Sujkowski points out as well that these rocks form only relatively thin series. Followed laterally, their corresponding time equivalents increase to far greater thickness. The accumulation of the radiolarian tests is extremely slow. Furthermore, the two contacting formations, above and below, indicate that the radiolarites as a series correspond in each case to a sedimentary cycle. From the more complete series above and below, he deduces the relative rates of deepening and shallowing of the water before and after deposition of the radiolarites. He points out that they are never found beyond the confines of the great geosynclinals. Furthermore, each geosynclinal records in its radiolarites a descent at least once into the depths. The Alpine reached its maximum descent in the Jurassic, the Hercynian in the Lower Carboniferous, the Caledonian in Lower Ordovician.

The more recent paper is quite comprehensive in its coverage of the general field of genesis and interpretations of environment, tectonic history, etc. In it the author compares the radiolarites of the Hercynian with those of the Alpine geosynclinal. The former were preceded by, those of the latter were followed by limestones indicating deposition in open and deep seas. Chemical analyses show essential identity. The former are characterized by bituminous matter in shales and cherts, while the latter bear ferric oxide in their jaspers. The former carry concretions of phosphate resembling apatite in composition and the latter contain manganese dioxide concretions. Thus the exclusion of oxygen in the depositional environment was not necessarily universal. The oxygen is of course possibly later in age. The Alpine deposits carry a greater number of species of radiolaria and the tests have shorter and stouter spines. Depth of water increased slowly and decreased rapidly in the case of the Hercynian deposits while the contrary conditions were deduced from the Alpine.

Diagenesis, in the simplest case, consisted mainly in the transfer of silica from some beds, thereby impoverishing them, to others, which were consequently enriched. The latter became the cherts or jaspers and the secondary silica was deposited in the interstices around the minute tests. Those impoverished in silica became the shales. Proof that they were originally composed in large part of siliceous tests rests upon the concretions which are filled with the fossil forms. The silica of the tests and that of the secondary deposit are different physically. Polished surfaces may be differentially etched by HF or KOH, or, in the case of the concretions, with HCl or HNO_3.

Comparison of the analyses of the modern muds with those representing the radiolarian cherts or jaspers shows an excess of silica in favor of the fossil types. Sujkowski points out that such comparisons are unfair because of the effects of the diagenesis. No excess will appear if the analyses compared represent the complete series involved in each case.

In some instances radiolarites have suffered severe alteration and have been totally replaced by calcite or dolomite.

The reviewer was interested in particular by a bare reference to the fact that extrusive igneous rocks are sometimes associated with the radiolarites. Sujkowski goes no farther in the French resume.

The papers are illustrated by a number of plates showing the natural exposures, as well as photomicrographs of thin sections and etched surfaces.

The reviewer commends the papers to students in the specialized fields contacted as well as to the general geologist. It is to be regretted that the real test is in the Polish language which is rarely understood by the general run of geologists of America.

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Schoep, A., Hacquaert, A. L., and Goossens, A., *Recherches sur quelques Roches carbonatées a grain fin et sur*

des calcaires oolithiques du Katanga. Annales du Service des Mines, Comité Special du Katanga, Tome 111, Brussels, 1932, 56 pp., 1 pl., 39 figs. *Recherches lithologiques sur des Roches carbonatées du Katanga,* Annales du Musée du Congo Belge, A. Minéralogie, Géologie, et Paléontologie, Série 1-Minéralogie, Tome 11, Fascicule 1, Tervueren, 1932. 104 pp., 1 pl., 71 figs.

As is common in districts which have been little studied, certain carbonate rocks of the same facies in Katanga, Belgian Congo, Africa, have been regarded as belonging to the same stratigraphic horizon, and have generally been correlated with a carbonate formation of the region designated the "Calcaire rose." The various outcrops which have been grouped under this name directly overlie the "Petit Conglomérat," which is the basal member of the upper series of the Kundelungu system of undetermined age, but thought to be perhaps early Paleozoic. Macroscopic examination of the carbonate rocks assigned to the horizon of the "Calcaire rose" gives no basis for their differentiation. The sole fossil remains heretofore recognized in the district are supposed algal forms. This absence of fossils, coupled with a lack of detailed lithologic study, has led to failure to realize that the carbonate rocks of Katanga are in many cases not parts of the same horizon.

The first paper, through a study of thin sections and the insoluble residues from the true "Calcaire rose" and also from a number of samples of carbonate rocks generally thought to belong to this horizon, presents the evidence that the carbonate rocks having the general macroscopic appearance of the "Calcaire rose" are possible of differentiation on the basis of the microscopic characteristics into a series of very definite types which the author designates calcareous schists, talcose dolomites, feldspathic dolomites, nodular limestones and micro-breccias, whereas the true "Calcaire rose" should invariably be either a dolomite or a dolomitic limestone. It is shown in particular that an oolitic facies which has been considered to be the "Calcaire rose" actually belongs about 1500 feet higher in the column. The supposed algal remains in the Kundelungu system are thought by the author to have had an inorganic origin. Traces of fossil matter, provisionally identified as *Tentaculites,* have been noted in some of the carbonate rocks of the Tantara district of Katanga and if the identification is correct the position of the containing rocks is in the middle Paleozoic.

Considerable attention is given to the oolitic carbonate rocks. The oolites are placed in two groups of which those of one group have concentric structure and those of the other radiate structure. It is suggested that those of concentric structure were developed by flocculation of colloidal or semi-colloidal matter, either organic or inorganic, in a shallow-water mud. Several of the oolites of concentric structure seem to have poorly-defined radiate structure in the individual laminations. The nucleus is never a foreign mineral. Some of the oolites of concentric structure have been considered of organic origin, but the author does not believe that such is the case.

Of the oolites or pseudo-oolites of radiate structure, some are stated to have been formed through alteration of oolites of concentric structure by means of recrystallization directed from the center toward the exterior following radial directions of least resistance. In several instances the concentric structure is still visible. Others of this group are believed to have been produced by crystallization of carbonate matter in the midst of a shallow-water mud of colloidal character. In the first of these methods of origin the spherical body has a crystalline center, in the majority of the specimens studied. In the second case, there is a microgranular opaque center.

Inclusions are not uncommon in the oolites of both groups. For purposes of

comparison oolites of other regions are considered and illustrated.

The second paper deals with much the same material as the first. A large number of the carbonate rocks were studied in thin section and by means of insoluable residues. For each rock the mineralogical data as to the carbonate content, the accessory minerals present and the percentage of insoluable residue are given, together with textural characteristics. It is believed that certain rocks of determined position in the stratigraphic column of the district may be correlated provisionally by means of certain typical textures.

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DACHNOWSKI-STOKES, A. P. Peat Deposits in U.S.A., *Handbuch der Moorkunde,* Bd. VII, 1933, pages 1-140, Pls. I-IX.

This work is a rather complete consideration of the peat lands of the United States. These are placed in three classes: oligotrophic, mesotrophic and eutrophic. The oligotrophic lands have peats poor in mineral salts and an acid reaction. The mesotrophic have peats not so strongly leached as the oligotrophic and not so strongly acid in reaction. The eutrophic peats contain considerable mineral matter and have a neutral or alkaline reaction.

The oligotrophic peat lands are located in the northern, cool and humid regions of the northern part of the United States. The mesotrophic are situated chiefly along the eastern and western coasts, and the eutrophic group has its outstanding areas in the Florida Everglades, the flood plains of the lower Mississippi and in intermountane valleys of California, Oregon and Washington.

The oligotrophic peat lands are classified into two subgroups: the Laurentian in the basin of the St. Lawrence River in the United States and Canada, and the Columbian in the northwestern part of the United States in river valleys near the coast. The Laurentian subgroup has two series of peat profiles: the Algonquin and the Champlain, the former in the north-central area of the glaciated region and the latter in the northeastern part of the United States, especially along the eastern coast of Maine. The Columbian subgroup has the Cascadian series of peat profiles.

The mesotrophic group has an inland and a coastal subgroup, the former including the peat lands placed in Huron, Warren, and Iroquois series of peat profiles. The coastal subgroup has the Pamlico peat profile.

The eutrophic peat lands are divided into the Everglades, San Joaquin and Puget Sound series of peat profiles.

The work contains a bibliography of 157 titles.

The same author has an additional recent work on peat bearing the title *Grades of Peat and Muck for Soil Improvement,* published as Circular 200 of the U. S. Department of Agriculture, 1933, pp. 1-30. This work contains some of the material found in the larger memoir but its objective is directed chiefly to the use of peat and muck for soil improvement.

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